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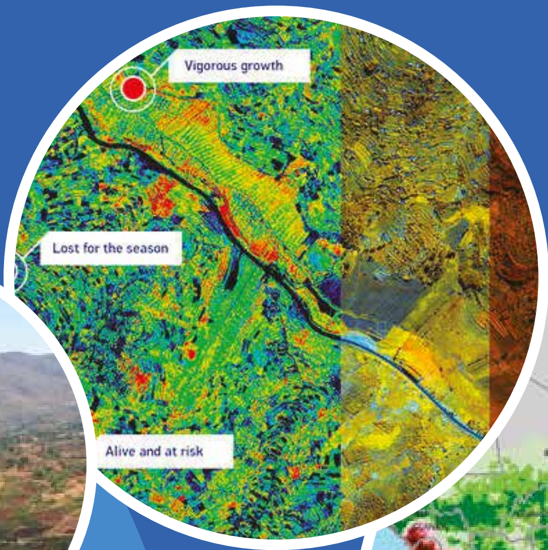
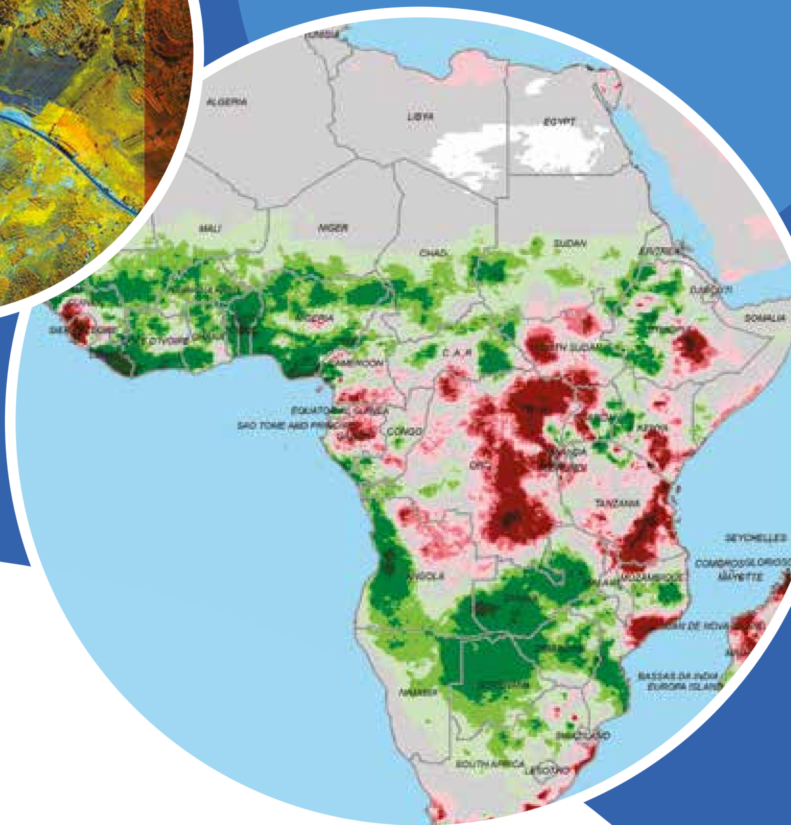
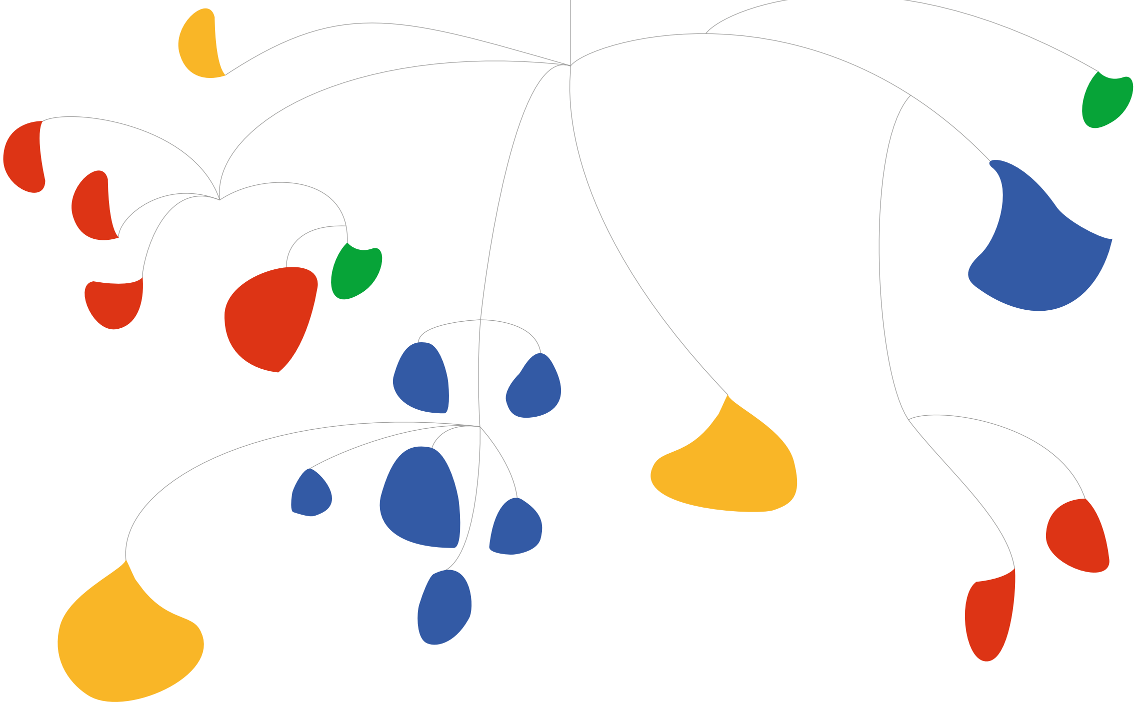




GUIDELINES ON THE USE OF REMOTE SENSING PRODUCTS TO IMPROVE AGRICULTURAL CROP PRODUCTION FORECAST STATISTICS IN SUB-SAHARAN AFRICAN COUNTRIES



GUIDELINES ON THE USE OF REMOTE SENSING PRODUCTS TO IMPROVE AGRICULTURAL CROP PRODUCTION FORECAST STATISTICS IN SUB-SAHARAN AFRICAN COUNTRIES

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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Contents

Acronyms

CHIRPS	Climate Hazard Group Infra-Red Precipitation with Station
CPC	Climate Prediction Center
DRSRS	Department of Resource Surveys and Remote Sensing
eMODIS	EROS Moderate Resolution Imaging Spectro-radiometer
ENSO	El Nino–Southern Oscillation
FAO	Food and Agricultural Organization of the United Nations
FEWS-NET	Famine Early Warning Systems Network
GDP	gross domestic product
GIS	geographic information system
GLCN	Global Land Cover Network
GeoWRSI	Geospatial Water Requirement Satisfaction Index Software
ILRI	International Livestock Research Institute
ISRIC	International Soil Reference and Information Centre
LU/LC	land use /land cover
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
RFE	rainfall estimate
SSA	sub-Saharan Africa
WRSI	Water Requirement Satisfaction Index

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Executive Summary

Agriculture is an important economic driver for sustainable development in Africa and employs between 60 and 80 percent of the country's rural population. The sector also contributes to food security, foreign exchange earnings and provides raw materials for agro-based industries in the region. For instance, it accounts for about 30.2 percent of the gross domestic product (GDP) in Kenya, 15.4 percent in Senegal, and 14.0 percent in Zimbabwe (World Bank 2014). Agriculture in most of African countries is largely rain fed, rendering productivity highly sensitive to climate variability and change.

There recently has been an increase in the frequency and intensity of extreme weather events, such as droughts, floods, strong winds and hailstorms, and an associated increase in pests and diseases, limiting the ability of the vulnerable households to produce food crops, especially in the marginal agricultural areas in most of the sub-Saharan Africa (SSA) countries.

Crop productivity in sub-Sahara Africa, including Kenya, Senegal and Zimbabwe is low and below global average levels (World Bank 2015). This is because production is dominated by smallholder farmers who are constrained by limited access to quality inputs and markets, limited access to credit, low use of appropriate production technologies and high food and energy costs. Despite the importance of crop production, and the associated challenges, Kenya, Senegal and Zimbabwe, similar to other countries in SSA, lack reliable and timely agricultural production forecasting systems to support decision-making at the national to household levels. These guidelines have been developed to facilitate the use of freely available remote sensing data and derived agro-climatic monitoring indicators and early warning products to improve crop production forecasting in SSA based on the recent experiences of the pre-selected countries – Kenya, Senegal and Zimbabwe. In-country trainings conducted by FAO consultants and supervised by FAO country teams in conjunction with local experts have resulted in key recommendations that are incorporated in these broad guidelines. To prepare the guidelines, the diversity in crop systems and institutional capacities across SSA was taken into account.

In preparing the guidelines, statistical correlation analysis was conducted between the historical data from remote sensing and derived products, and field based crop production estimates (acreage and yield) in the three selected countries. The correlation analysis focused on main staple food crops in these three countries (the main staple food crops are maize & beans, millet & maize, beans & maize in Kenya, Senegal and Zimbabwe, respectively). Failure in the production of these staple crops often translates to food insecurity.

Key considerations in the development of the guidelines were thus based on:

- Building on existing national crop production assessments and forecasting systems – strengths and limitations; and
- Identification of new opportunities for timely, reliable and cost-effective improvement of the current systems based on more robust, but readily available indicators for regular and comprehensive crop assessments and estimation.

Additionally, the following key science questions were addressed:

- Which are the main staple food crops?
- Where are the food crops grown and under what prevailing conditions?
- What are the key indicators for assessing the cropping conditions and overall production?
- Which indicators, should be used, when, and where during the seasonal cropping calendars?
- What is the best-mix for the use of remotely sensed products, crop models and field assessments to support more robust, timely and reliable crop production systems?

The results of the analysis presented the following main outcomes:

- Staple food crop baselines – based on field validated remotely sensed products;
- Current crop production conditions and risks;
- Statistically significant indicators for crop yield and acreage assessments under different agro-ecological zones;
- Improved understanding of the linkages between crop production and agro-climatic conditions to support reliable early- crop production estimation scenarios; and
- Findings of the correlation analysis between the data from remote sensing and crop production estimates from the ministry of agriculture).

The present report provides baselines on staple crop zones and their attributes, such as crop calendars and climatic trends, which could form the basis for improved crop assessments and production estimation.

There is reasonable statistical correlation between field-based crop production (acreage, yield) assessments with readily available remotely sensed products and crop model outputs, thereby offering new opportunities for more objective approaches for timely and reliable crop production forecasting in Kenya, Senegal and Zimbabwe.

Thus, this report provides guidelines and a framework for developing multistage crop forecasting systems built on existing national institutions, but also leveraging on new technical advancements in a sustainable manner. In explaining the first and the critical step of the process, namely establishing the baselines, examples from Kenya, Senegal and Zimbabwe are considered and explained in detail in the report

In the document, it is recognized that there are general limitations in using the approaches prescribed, especially those relating to field assessments and indirect remotely sensed observations and their derived products.

Also recognized in the document is that no single independent indicator can provide timely and cost-effective modalities for assessing cropping conditions and estimating production under diverse cropping conditions and management practices.

Therefore, one of the recommendations in the document is for the establishment of an elaborate multistage crop production forecasting system resulting from the convergence of evidence approach in assessing and generating crop production estimates based on remotely sensed products and use of crop modelling outputs validated with field assessments in areas of concern during a cropping season.

Furthermore, the importance of rigorous field based early-, mid- and post-season assessments aimed at systematically improving the crop production estimates in tandem with changing agricultural practices and assessment techniques is underscored in the report.

It is hoped that this approach will ensure optimal utilization of remotely sensed derived products and crop model outputs, which, in turn, will support well-targeted and efficient field crop assessments at the subnational level during the crop-growing season. Ultimately, it is hoped that this approach will result in field validated (objective), timely and reliable agriculture production assessments and estimates.

1

Introduction

The importance of timely and reliable agricultural production forecasts cannot be overemphasized in making informed food policy decisions and to allow for rapid response to emerging food shortfalls and market stabilization, especially in SSA, which is becoming increasingly vulnerable to high food prices and food insecurity crisis. The drivers of these high prices and food insecurity are both climatic and non-climatic and are often aggravated by subjective and unreliable agricultural production assessments and forecasting systems. An inaccurate and delayed agricultural production estimation often leads to bad and costly decisions and policies at national and regional levels, resulting in unnecessary human suffering and, at times, loss of lives.

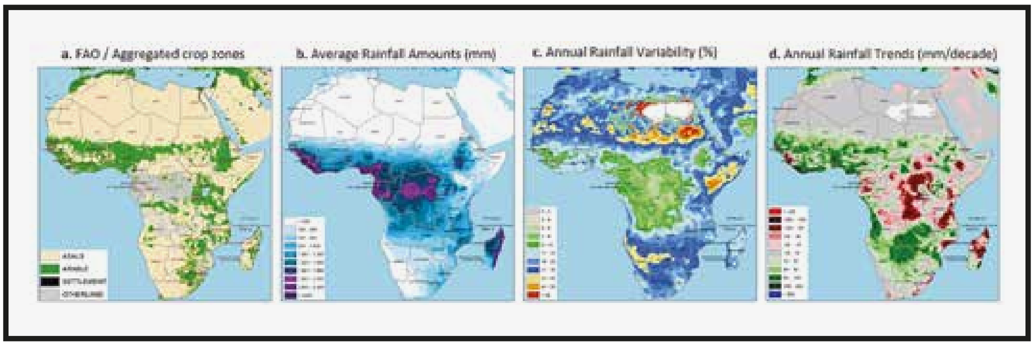
The demand for more objective and reliable forecasts with adequate lead-time to facilitate appropriate response and contingency planning continues to increase. Coupled with this, is the demand for increased institutional capacity development within national ministries and in-line agencies responsible for agriculture.

Agricultural production forecasting is the science of reliably estimating potential production with an adequate lead-time. Several approaches for agricultural production forecasting are currently being used in SSA. They vary from fairly subjective to more statistically objective techniques depending on available technical and financial resources.

In recent years, new approaches have been developed that integrate available field and remotely sensed observations (rainfall, temperature, soil moisture and vegetation) with simple crop-specific water balance models to generate timely and more reliable agricultural production monitoring and forecasting indicators. These also are used in auditing field assessment reports by in-line ministries and other partners.

Increasing variability in seasonal crop production occasioned by high rainfall variability and change trends (mostly rainfall), coupled with limited financial and skilled human resources to mitigate the effects of these erratic climatic patterns are major challenges for small and commercial farmers, in terms of planning and guaranteeing optimal crop production. For the mandated national agricultural agencies, this makes it difficult to comprehensively assess and provide reliable crop production forecasting amid high variable spatial seasonal rainfall patterns, exacerbated by declining rainfall amounts in vulnerable marginal agricultural areas in SSA. As illustrated below, the baselines generated using FAO (Africover/land use-land cover) and FEWS NET datasets (CHIRPS2.0) allude to the importance of continuous and comprehensive crop assessments and production estimates.

Figure 0
Baseline maps on Africa crop zones, annual rainfall variability and trends based on satellite-derived products



This **document** advances country-specific guidelines to support reliable and timely agriculture production assessments and forecasts at the subnational to national level during crop growing seasons. The cornerstone of this document is hinged on building on existing agriculture production monitoring and forecasting systems – based on existing methods used by the ministries of agriculture in the three preselected countries. This is then boosted by the inclusion of new opportunities offered by readily available remotely sensed observations, validated crop model outputs and geographic information system (GIS)-based analytical tools. The emphasis of this document is on developing user-specific skills based on a step-by-step modular approach, driven by seasonal cropping calendar activities, and their associated phenological stages to assess and determine crop production forecasts at each crop critical stage. At each stage of the assessment and forecasting and estimation, the guidelines focus on convergence of evidence gathered from independent data-streams – mostly from remotely sensed observations and products, backed by well-guided area-specific field assessments. Post-harvest assessments form a critical part of the guidelines for creating a better understanding of emerging challenges and new opportunities for systematically improving this multistage crop assessments and forecasting system.

Goal

The aim is to **improve agriculture production forecasting** systems at the subnational level and aggregated at national-level. Crop production is expressed as:

Crop production = function (Acreage * Yield)

Acreage Estimation is perhaps the most challenging aspect in crop production estimation and forecasting because of the lack of adequate resources to undertake rigorous agriculture field area surveys across the country, especially in most SSA countries with smallholder farm sizes. For this reason, readily available field, aerial and satellite based agricultural zones maps are used to generate acceptable crop zones maps and baselines. The crop zone maps serve as baselines and can always be validated and updated over time based on regular extensive field officer assessments conducted by ministries of agriculture and also through change detection analysis using RS technology.

Yield Estimation is a function of the quality of cropping conditions, prevailing environmental (degradation and pests, among others) and crop management. There are inherent large disparities among these factors across SSA. Applying evidence-based analysis using readily available, but independent data streams to support yield assessment is highly recommended in this approach. This has, of course, to be backed up by well-guided, regular and cost-effective rapid field assessments by ministries of agriculture extension officers.

Production Estimation can then be achieved with timely and reliable estimation of acreage and yield at each critical crop phenological stage, thereby ensuring an accurate crop production forecast with adequate lead-time to support decision-making at the subnational to national-level.

Objectives

Overall, this document is focused on developing an in-depth understanding of agricultural production systems in Kenya, Senegal and Zimbabwe as an example and provide guidelines on:

- Identifying and recommending reliable crop zones/masks for main staple crops; Characterizing key crop production systems and trends at the subnational level.
- Linking climate variability and change to crop production (acreage and yield) trends and risks;
- Undertaking statistical analysis of field based crop production (ministry of agriculture statistics) and remotely sensed products and crop model outputs with a view to determining the correlation between the freely available remote sensing data and crop production estimates;
- Assessing the strengths and weaknesses of various available independent data and products streams in multistage crop production assessments and forecasts; and
- Recommending best-practices in crop production forecasting based on remotely sensed products and well-targeted field assessments using ministry of agriculture extension officers.

2

Approach and datasets

2.1 Approach

Owing to the size and diversity of SSA cropping systems and agricultural institutions, this guideline is based on the study undertaken in Kenya, Senegal and Zimbabwe, which are considered representative of eastern, western and southern Africa sub regions, with diverse agro-ecological and crop production systems.

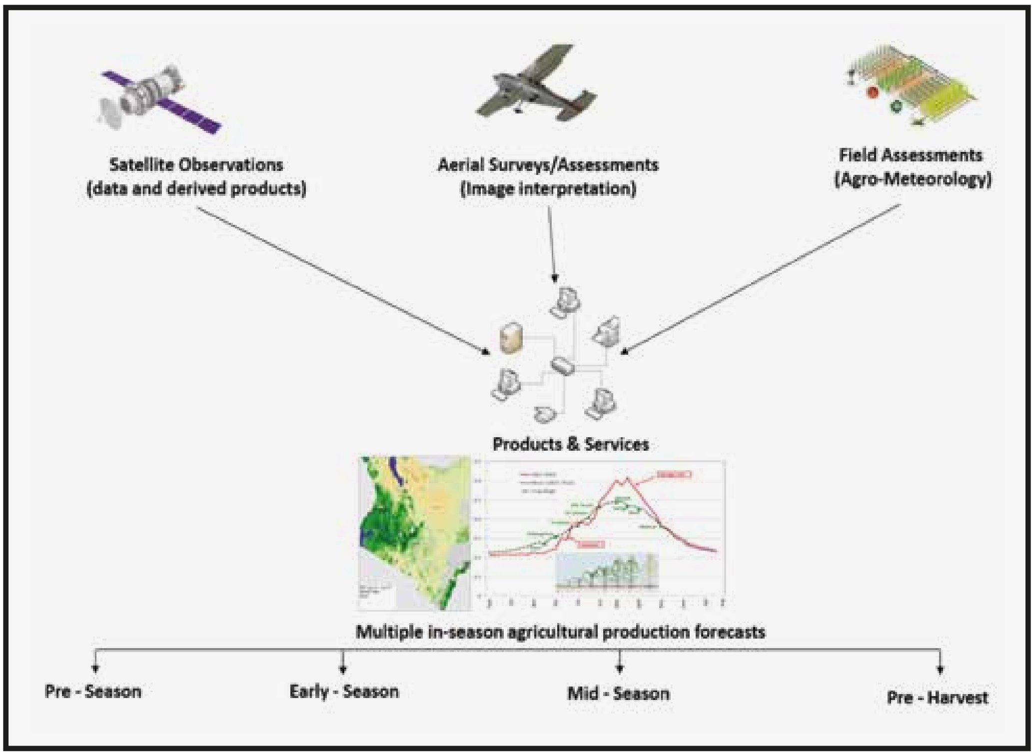
Furthermore, these three countries are faced with recurrent food insecurity conditions of varying severity and scale (extent and duration) because of insufficient food availability from their own production, unaffordable and highly volatile food prices, and at times, insufficient nutritional food to support human well-being. The main food insecurity drivers are both climatic and non-climatic factors (high population growth rate, policies, governance, conflict, diseases and pests). The food availability problem is exacerbated by the lack of timely and reliable agricultural production forecasts to support contingency and response planning at the subnational to national-level.

The approach articulated in this guidelines document is anchored on **building on and integrating the existing agriculture production systems** (illustrated in Figure 2).The guidelines considers the crop production forecast statistics system in these three countries. The ministries of agriculture in these three countries have **historical agriculture production statistics** as well as experience and skills in agricultural assessments and monitoring and early warning.

Their main limitation lies in the integration of field assessments with readily available remotely sensed observations and products and crop model outputs for improved and more objective assessments and estimates. The use of **satellite imagery** varies across the three countries with Kenya (the Directorate of Remote Sensing and Resource Surveys) additionally using aerial photography, which, however, remains costly. As a result, the surveys cannot be conducted regularly, particularly during critical crop stages. Meteorological services in

the three countries regularly undertake **agro-climatic monitoring, early warning and reporting**. This is important as the three countries rely on rain fed agriculture for their staple crops, namely maize and beans in Kenya, millet and maize in Senegal and maize and beans in Zimbabwe. The key challenge in all the countries is the lack of sustainable integration of the stakeholders' information in agricultural production monitoring and forecasting.

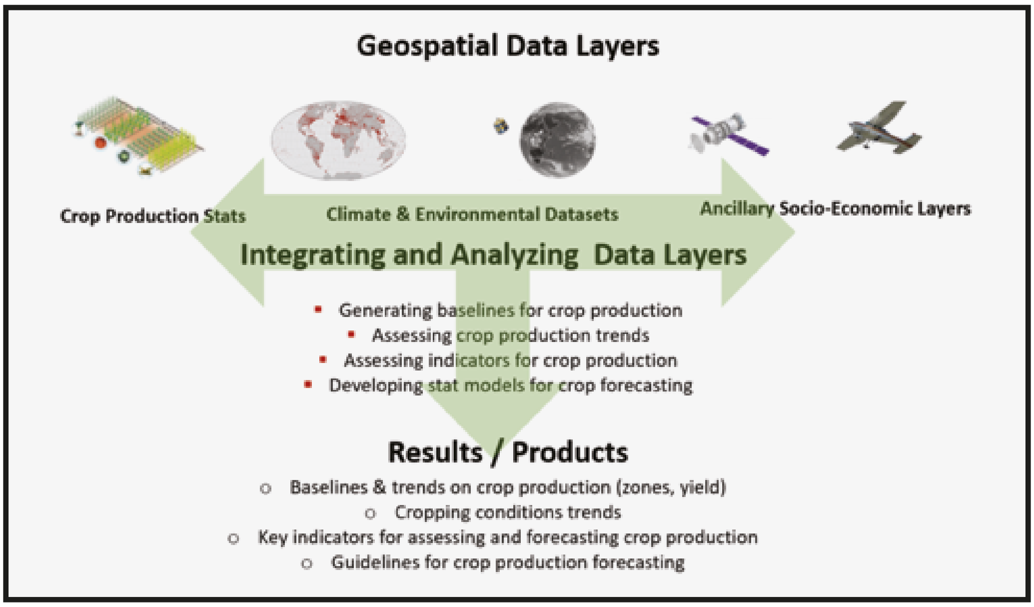
Figure 1
Integrated agricultural production forecasting based on satellite observations, model outputs and field assessments



2.2 Datasets, analysis and forecasting

The flow diagram below (Figure 3) helps to explain the geospatial integration of various layers of readily available data to support analysis, with key questions and outcomes expected to support improved assessments and forecasts, supplemented by regular but well-targeted field assessments in the three countries. This approach is being applied in some of these countries to some basic level.

Figure 2
Conceptual flow diagram illustrating the geospatial integration and analysis of available agricultural products datasets and indicators and expected results.



To assist in demonstrating the effectiveness of this approach, the main datasets used in the three pilot-countries are sourced from:

- Ministries of agriculture (and in-line agencies – the mandated national source for agricultural production statistics in the three countries,
- Satellite and space agencies that provide remotely sensed observations and derived products; and
- United Nations agencies and non-governmental organizations that work within the countries supporting improved crop production assessments and forecasting (FAO, World Food Programme, United States Geological Survey/FEWS-NET, local and international Universities, among others).

The latter have geoportals that provide regular updates on various agro-climatic indicators and reports. In some countries, these have been used in validating the agricultural production statistics generated by the ministry.

In summary, the following datasets from various datasets were found to be useful for this approach:

Institution / agency	Datasets	Variable (staple crop)	Spatial and temporal scale	Comment
Ministry of agriculture	Crop production estimates	Acreage yield production	Subnational level and seasonal to annual time-scales	Available, but, with inconsistencies in time and scale.
National Meteorological Services	Agro-climatic and seasonal forecasts.	Rainfall, temperature and Evapotranspiration (ET).	At station locations on daily basis. Seasonal forecasts provided with homogeneous climatic zones and agro-met reports on decadal to monthly basis.	Climate datasets available, but, sparse in marginal cropping areas. There are restrictions in data sharing and exchange.
Satellite and space agencies	Agro-Climatic indicators		RFE2.0, TAMSAT/RFE, CHIRPS, CHIRTS, ET, eMODIS/NDVI, Spot/VGT, SAVI, VegT, WRSI, among others	Readily available at 250m for NDVI and 5-10km resolution for CHIRPS, RFE, PET and WRSI.
In-line ministries and agencies	Varied	Agronomic practices, pests, diseases, crop production	At the subnational level	Available in some ministries of agriculture and ad -hoc assessment partner reports (FAO, FEWS NET, Met Services)

In the review stage of this study, it was noted that the above stated datasets are of varying temporal and spatial scales. However, because agricultural practices are constantly changing, coupled with changes in key ancillary datasets, such as administrative units, it was considered useful to focus much of the analysis on the period 2001-2015. Even, with this consideration, there were data inconsistencies in time, space and quality.

The crop production datasets derived from satellite observations and crop model outputs were generally more readily available and consistent over time and space at the United States Geological Services/FEWS NET and FAO/GIEWS geoportals:

- http://early.warning.usgs/fews
- http://www.fao.org/giews

However, their main limitation of these indirect satellite based observations and their derived information is that they needed to be field-validated regularly.

With these remotely sensed products and field observations, the approach (geospatial analysis with active stakeholders' field validation) or the guidelines entail the following six steps:

1. Generating Agricultural production baselines:

- Where and under what conditions are crops grown in the country?
- Publishing baseline and reference maps at the subnational level showing current crop zones, density, acreage, production, trends and contribution to national production.
- Delineating irrigated areas (for purposes of masking out these areas and using appropriate assessment indicators).
- Generate seasonal agro-climatic trends maps within the cropped zones; averages, variability's and trends based on national rainfall/RFE/CHIRPS, the Normalized Difference Vegetation Index (NDVI) and WRSI datasets.
- Generate county-specific crop calendars and length of growing period maps.

2. Pre-season agricultural production forecasting and contextual interpretation:

- **One-month before the start of the season** – Interpret seasonal climate forecasts into quantifiable rainfall amounts, anomalies and crop suitability (based on the crop's water requirement amounts)
- Use selected analog years to generate crop production scenarios based on historical GeoWRSI model runs for identified analog years, historical ministry of agriculture production statistics and expert advice.
- Estimate potential crop production prospects at the subnational level and aggregate to the national-level, as the pre-season agriculture production forecasts.
- Identify cropping areas at risk based on the forecast agro-climatic conditions for close monitoring and updating during the cropping season.

3. Establishment of start of season/planting forecast

- **One-month after the start of season**, assess the establishment of the onset of rains and planted acreage based on:
- GeoWRSI/Start of Season, eMODIS and/or Spot/NDVI anomalies, identify and delineate areas of significantly delayed onset (> one month).
- List and generate maps of delineated areas and acreage estimated, and, share with the ministry of agriculture extension officers for rapid assessment and validation.
- Generate estimated acreage planted at the subnational cropping zones and aggregate at the national-level and report during this period.

4. Crop establishment stage:

- **Two-months after the start of the season** – assess the establishment of crop and conditions, based on:
  - Start of season maps and NDVI profile graphs – identifying areas of significantly delayed onset (more than one month).
  - Assess and delineate areas of significant crop stress (WRSI > 50 percent), and, where applicable, convergence of evidence with NDVI anomalies and soil moisture maps, and/or loss through flooding and disease and pests.
  - List and generate maps of delineated areas at risk of crop losses, acreage and early season yield estimated, and share with ministry of agriculture extension officers for rapid assessment and validation.
  - Generate updated estimated acreage planted, potential yield at subnational to national-level and report on revised crop production estimates.

5. Crop maturity stage agriculture production forecast (varied with length of the growing period)

- **Three to four months after the start of the season** – assess the ongoing cropping conditions and prognosis for the end of season at this critical crop stage (for early maturing crops) based on:
- WRSI and WRSI/end of season anomalies maps – identify areas of continued delayed/failed onset, crop stress and forecast crop failure (50 percent < WRSI/end of season anomalies < 253 percent). The thresholds provided are indicative of WRSI values.
- Assess and delineate areas at risk of crop failure using convergence of evidence based on NDVI and soil moisture anomalies, and/or loss through, for example, flooding and disease and pests. **It is recommended that this is supported by rigorous field assessments at this critical stage**.
- List and generate maps of delineated areas at risk of crop losses, acreage and yield estimated, and share with ministry of agriculture extension officers for rapid assessment and validation.
- Generate first reliable crop production estimates at subnational and national-levels and publish an actionable report with adequate lead-time in support of decision and policymaking.

6. Post-harvest assessments:

- Four to five months after the start of the season – guided by the subnational crop calendars (earlier generated) – undertake post-harvest assessments, otherwise, continue with crop assessments for the long-cycle crops, until the end of their cropping season:
  - **If**, the cropping season has ended – discuss and generate final crop production estimates, **evaluate and recommend new improvements in the approach of agricultural production forecasting system in the cropping zone**.

- **Otherwise**:
  - WRSI and WRSI/end of season anomalies maps – identify areas of continued delayed onset, crop stress and forecast crop failure (50 percent < WRSI/ER Anomalies < 253 percent).
  - Assess and delineate areas at risk of crop failure, using convergence of evidence based on NDVI and soil moisture anomalies and or loss through flooding, disease/ pests.
  - List and generate maps of delineated areas at risk of crop losses, acreage and yield estimated, and share with ministry of agriculture extension officers for rapid assessment and validation.
  - Continue to update crop production estimates at the subnational to national-level and revise the report accordingly, until the end of their cropping season.

Figure 3
Computing national crop production prospects

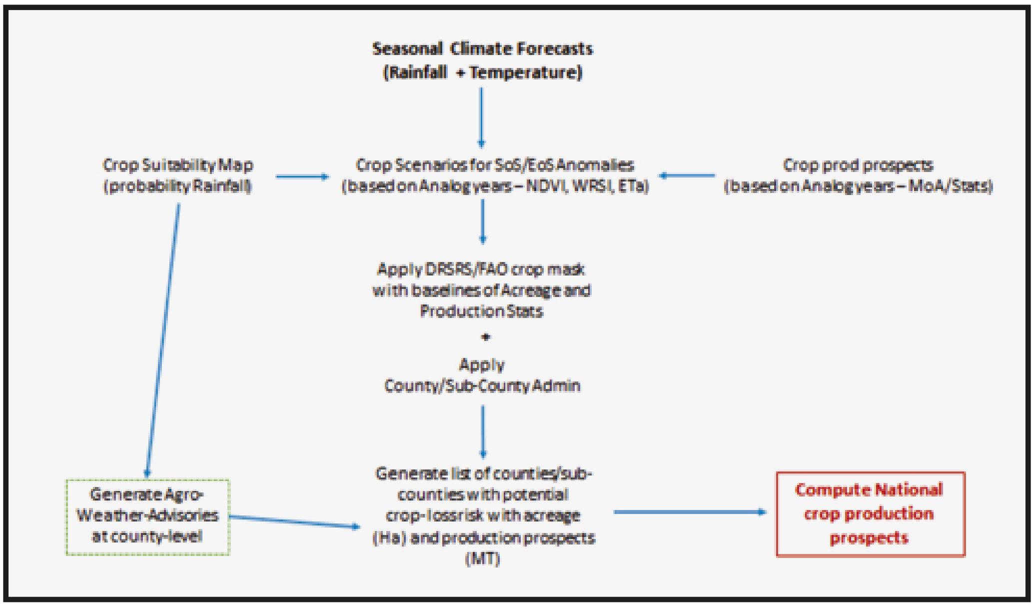
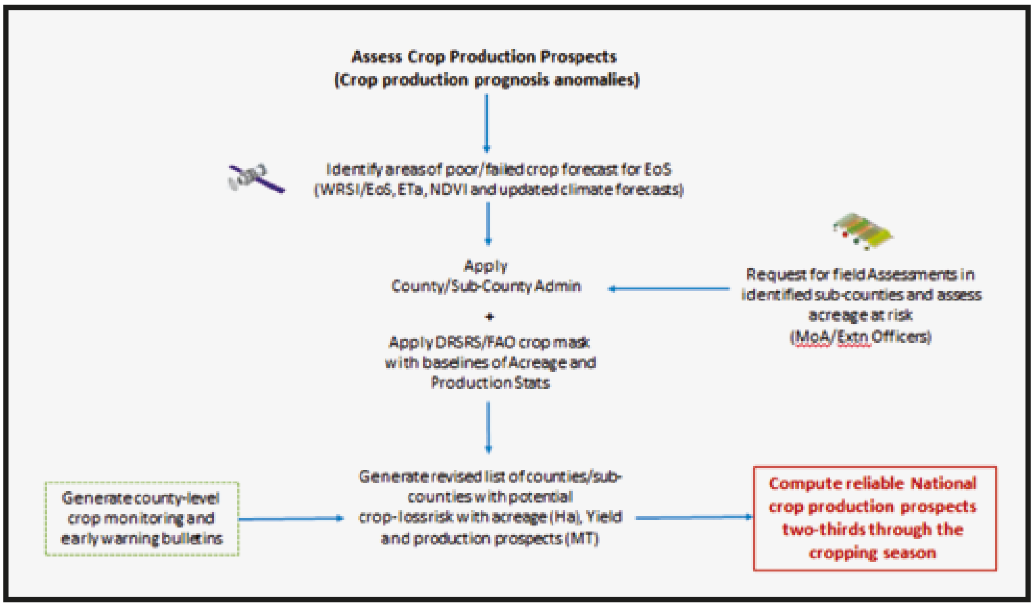


Figure 4
Computing reliable national crop production prospects two thirds through the cropping season



3

Agricultural production baselines of key staple crops

3.1 Baselines

In defining, the national staple food crop(s) zones and their attributes (baselines), an analysis of available datasets on agricultural production statistics from the ministry of agriculture , agro-ecological zones, livelihood zones and profiles, together with remotely sensed land use/ land cover (LU/LC) and aerial surveyed maps, where applicable, are assessed.

The analysis described in this section focused on key food staple crops in Kenya, Senegal and Zimbabwe to demonstrate the efficacy of the recommended guidelines, whereas, Kenya mainly depends on maize and beans, Senegal relies on millet and maize and the main staple crops of Zimbabwe are maize and beans.

The staple crop zones form an important basis for crop production assessments and production estimates in terms of where the key staple crops are grown and under what conditions and risks. Equally important is the determination of how much these cropping zones at the subnational level contribute to the overall national production. Crop zones, often referred to as crop masks, allow for better geospatial analysis and interpretation of remotely sensed products and crop model outputs and their efficacy as crop productions indicators.

In some countries, good and recent maps on LU/LC that have been validated and thus form an appropriate good basis for detailed analysis. In some of the pilot countries, the crop zones maps are more indicative, but fairly representative, for the intent and purpose of the analysis performed herein.

Because of the diverse landscapes/agro-ecological zones, and for purposes of clarity and to better informing regular crop assessments and forecasting, each country's baselines are described in separate sections to allow a detailed analysis and contextual interpretation of the baselines, trends and limitations.

It is against this background that Section 3.2 of this present document deals with three key aspects, namely, crop zones, trends, and limitations, in Kenya, Senegal and Zimbabwe.

3.2 Statistical analysis

Statistical analysis was undertaken using the national agricultural production data collected. The data were organized and interpreted to give insights on prevailing trends and how they correlate with readily available remotely sensed products and crop model outputs. The overall aim was to optimally use field and remote sensing datasets to assess cropping conditions and generate reliable and timely crop production (acreage and yield) forecasts.

The focus, of this analysis was on assessing the quantity and quality of seasonal rains, the variability and trends of the rains and their impact on crop production during seasonal growing seasons in the past decade or so. It was expected that statistically significant correlations between field observations with indirect satellite observations and crop model outputs would provide useful proxies for timely and comprehensive assessments of cropping conditions, which would, in turn, inform well-targeted and cost-effective field assessments conducted by ministries of agriculture extension officers and interested stakeholders and partners at critical crop phenological stages. The statistical correlations analysed here were between crop yield and rainfall and between vegetation indices and the Water Requirement Satisfaction Index (WRSI) within corresponding crop zones.

The datasets were also used to determine the cropping zones and seasonal crop calendars; from the start of season/planting, crop establishment, to harvest – based on independent data-streams, such as rainfall estimates and vegetation indices. The seasonal crop calendar is an equally very important tool for assessing seasonal cropping conditions and overall production as compared with the crop zones.

3.2.1 Kenya statistical analysis

Country context

Kenya, a country in East Africa bordering the Indian Ocean in the south- east, neighbouring countries are Ethiopia, Somalia, South Sudan, Tanzania, and Uganda. The total area of the country is 582,650 km^2 (*Encyclopaedia of Nations*). The country is subdivided into 47 counties.

The altitude of the country varies from sea level to the peak of Mt. Kenya, situated north of the capital Nairobi, which is 1,795m above sea level (*Wikipedia*). The soil types in the country vary from place to place due to topography, the amount of rainfall and the geological material. The average annual rainfall is 630 mm, with a variation from less than 200 mm in northern Kenya to more than 1,800 mm on the slopes of Mt. Kenya. The rainfall distribution pattern is mostly bimodal with long rains falling from March to June and short rains from October to November in most parts of the country. The climate is influenced by the intertropical convergence zone and relief and ranges from permanent snow above 4,600 metres on Mt. Kenya to true desert in the Chalbi desert in Marsabit County in the north of the country. About 80 percent of the country is arid and semi-arid, while 17 percent is considered to be high potential agricultural land, sustaining 75 percent of the population.

The country has six major agro-ecological zones: upper highland (UH), lower highland (LH), upper midland (UM), lower midland (LM), lowland (L) and coastal lowlands (CL). These zones are associated with corresponding temperature variations ranging from freezing to 40°C. The Penman estimate of annual evaporation from open water surfaces in Kenya varies from 1,000 mm in the central highlands to 2,600 mm in the arid north.

The agricultural land covers about 33 percent of the country and is classified as:

- High potential land receiving more than 850 mm of annual rainfall and covering 67,850 km^2.
- Medium potential land receiving between 730 and 850 mm and covering 31,570 km^2.
- Low potential land receiving less than 610 mm and covering 42,050 km^2.
- Others covering 48,670 km^2

The high and the medium potential land is considered cultivable, covering an area of 99,420 km2 or almost 10 million ha.

Kenya baselines: staple crop zones and attributes

Various available national geospatial datasets and historical crop production statistics were used in the analysis to assist in delineating and characterizing key staple food crop production systems in Kenya. The country has the distinct advantage of being fairly data rich – a situation that allows for more detailed comparative analysis and characterization of crop zones, owing to the availability of the following pertinent datasets:

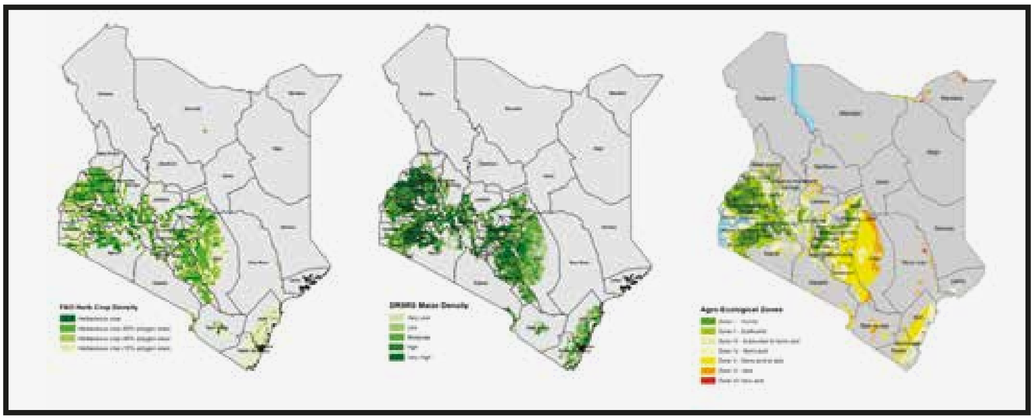
- FAO/Africover aggregated herbaceous crop maps (1999/2000);
- National Ministry of Agriculture agricultural production statistics for the past decade
- Maize coverage and density maps based aerial survey (early 2006) produced by the Directorate of Resource Surveys and Remote Sensing;
- Agro-ecological zones maps from International Livestock Research Institute (ILRI) and Directorate of Resource Surveys and Remote Sensing;
- Other, relevant sources – United States Geological Survey land cover maps (based on freely available Landsat and eMODIS datasets;
- FEWS NET markets and trade flow maps, and
- Livelihood zones maps and profiles (recently updated)

Kenya maize and beans zones

A comparative analysis of the 2006 Directorate of Resource Surveys and Remote Sensing maize density (based on aerial photo-interpretation) and 1999/2000 FAO aggregated herbaceous crop map (generated from Landsat and high resolution satellite data and locally validated) provide detailed analyses on locations where there is increased likelihood for maize and beans cropped areas and crop densities, which is often related to climatic and environmental conditions and subsequently yield patterns. Most of these crop zones are often intercropped with beans and other legumes, especially in moderate to low rainfall regimes.

As seen in Figure 5, the 1999/2000 FAO and 2006 Directorate of Resource Surveys and Remote Sensing maps are very similar and provide high confidence of potential cropping areas, with little or significant changes despite the fundamental differences in methodologies of delineating the cropped zones. These products require regular updates, due to changes in land use-land cover patterns.

Figure 5
Maize crop zones based on Directorate of Resource Surveys and Remote Sensing DRSRS and FAO-Africover aggregated herbaceous, and, attributed to gro-ecological zones.



Recent crop-tour assessments by United States Department of Agriculture, FEWS NET and partners in the period 2006-2008 helped in validating the above crop zones as useful geospatial layers to form the basis for regular crop assessments and estimation. Similarly, the Kenya Food Security Steering Group has been conducting regular mid- and post-season crop assessments in arid and semi-arid lands, where the crop production is highly variable because of prevailing climatic and environmental conditions.

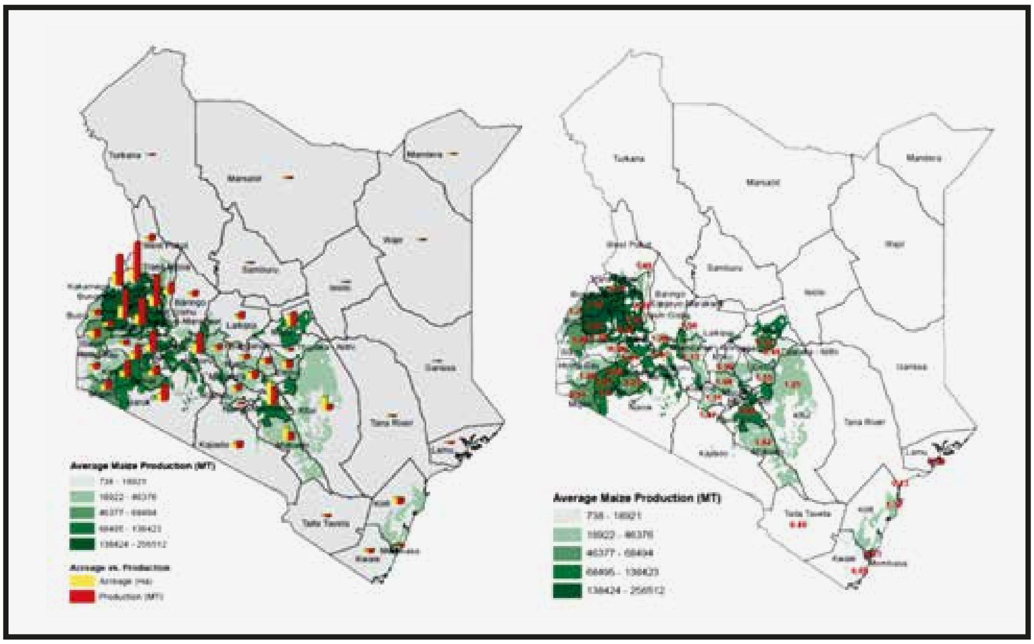
Characterization of crop zones in Kenya

The historical crop production trends within the delineated crop zones depict the following main characteristics:

- Low inter-seasonal variability in maize production in terms of acreage and yield in high potential areas, mostly in north rift valley areas, western Kenya and parts of the central highlands and southern rift valley. On average, this main maize belt accounts for about 70 percent of the annual maize production.
- Medium maize production areas are mostly confined within parts of central and southern rift valley and the coastal strip, which account for about 15 percent of the national production.
- The high and medium production areas, overall account for more than 85 percent of the total national production. Thus, in case of crop failure, this could translate to serious food shortfalls.
- The low productions areas are confined to the south-eastern lowlands and parts of coastal strip of Kenya, where mixed farming occurs because of limited and highly erratic rainfall seasons and rainfall amounts. This area accounts for less than 10 percent of the national productions and is often prone to maize and beans crop failures.
- There is evidence of a strong correlation between maize crop density and the Ministry of Agriculture production patterns.
- The map of the agro-ecological zones (Figure 5), depicts variations in each cropping zone, with the marginal cropping zones over the south-eastern lowlands, north-eastern and parts of the coastal areas, clearly falling within the semi-arid to arid zones.

Figure 6 illustrates maize crop production trends, yield characterization, acreage patterns, and production contribution by county within the delineated maize zones of Kenya.

Figure 6
Maize crop production trends, characterizing yield, acreage patterns and production contribution by county within the delineated maize zones.



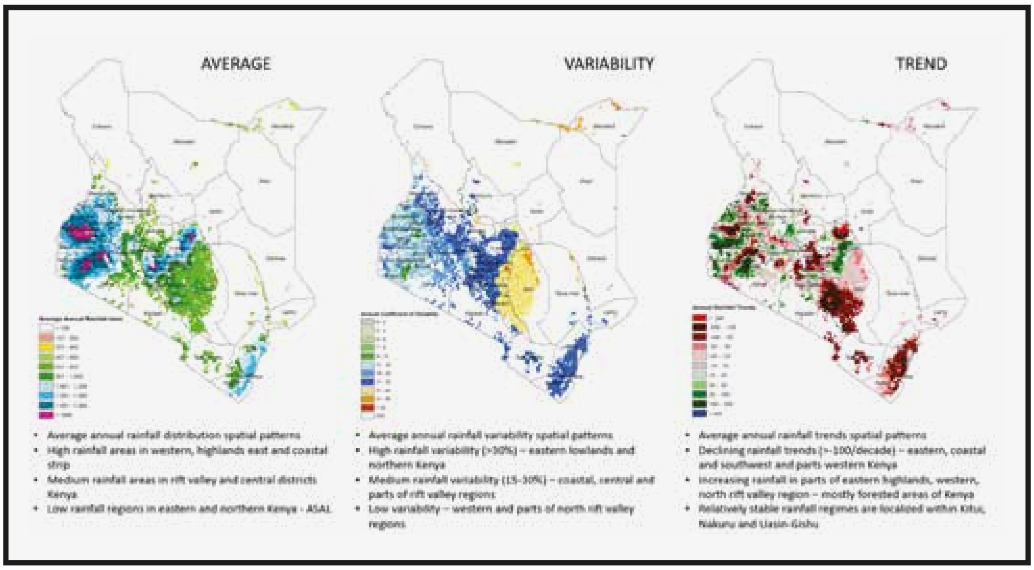
Because of the expected changes in crop zones, the Regional Centre for Mapping of Resources for Development through the United States Agency for International Development-funded SERVIR project, is currently revising the FAO/Africover crop mask based on freely available Landsat images from 2014 to 2015 and high resolution images, using the FAO Land Cover Classification System approach. This updated product is expected to help in validating and identifying changes in Kenya crop zones baselines. Furthermore, the FEWS NET project has also been collaborating with the Regional Centre for Mapping of Resources for Development to provide historical maize crop model outputs and is now available on SERVIR servers to support maize crop drought risk mapping for the period 1981-2015.

Climatic trends within maize zones

Because of high dependence on rain fed agriculture for crop production in Kenya, variation and changes in climatic and environmental conditions are expected to affect the production of maize and beans.

To support this part of the study, available recent blended climate datasets (rain gauge and remotely observations) were used to analyse the climatic conditions under which the maize crop is being grown in Kenya (Figure 7). This, together with livelihood profiles, provided useful insights into the prevailing cropping conditions, climatic hazards and implications to crop production and livelihood systems.

Figure 7
Annual rainfall distribution patterns – amounts, variability and trends and potential impacts on rain fed cropping conditions



Similar analysis was undertaken at seasonal time steps to assist in characterizing seasonal rainfall trends and their implications to crop production at the count -level (Figures 8 and 9).

Figure 8
Long-rains (March- May) seasonal average rainfall amounts, variability and trends

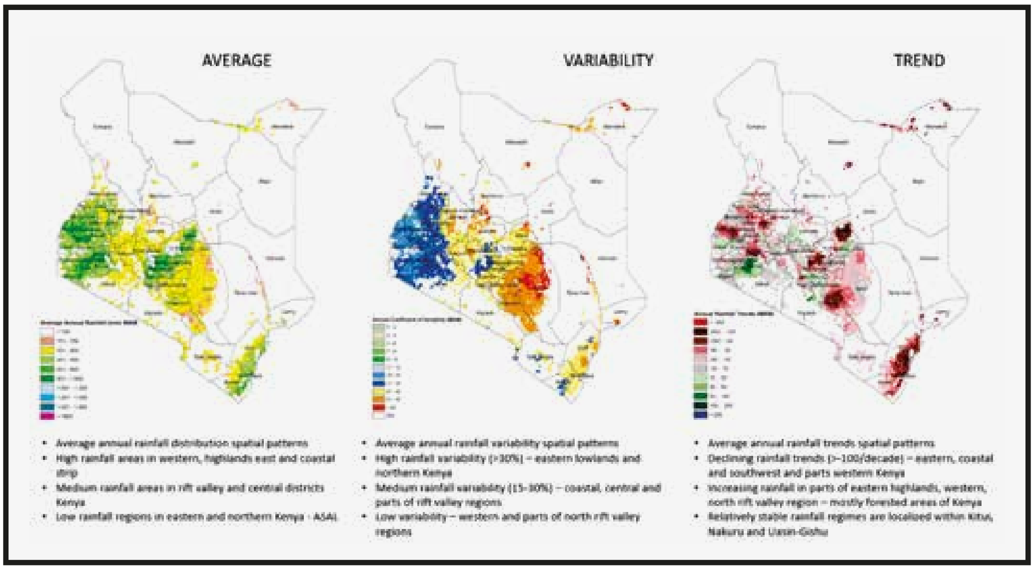
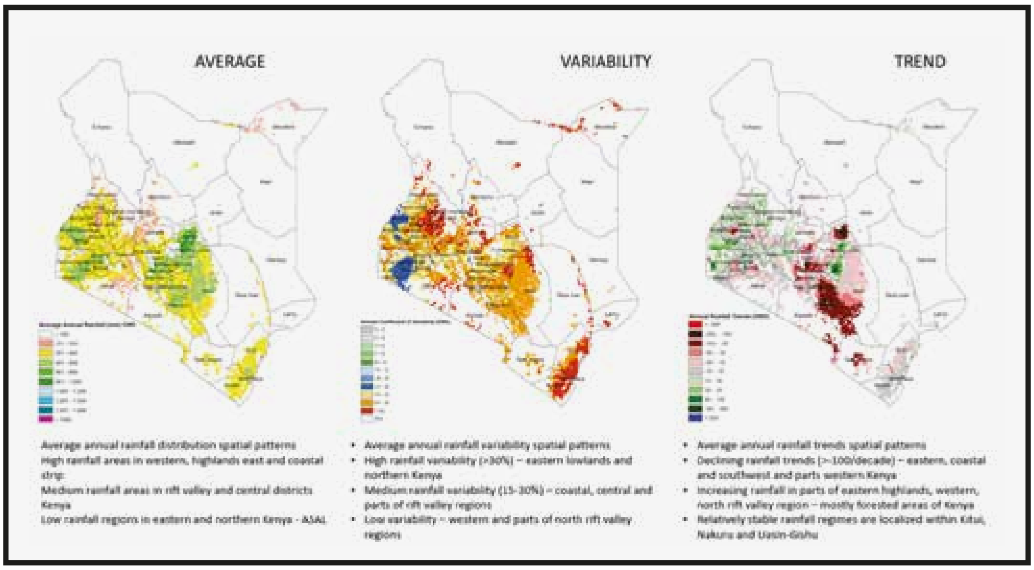


Figure 9
Short-rains (October-December) seasonal average rainfall amounts, variability and trends



Overall, the seasonal rainfall patterns and amounts provide insight as to which season is important, where it is important, and the potential implications to crop production. However, the analysis lacked information on the quality of the season (number of rainy days, dry and wet spells) based on intra-seasonal rainfall distribution and its impacts on yield and acreage harvested at the end of the cropping season, especially in marginal cropping areas over eastern and localized areas in northern Kenya.

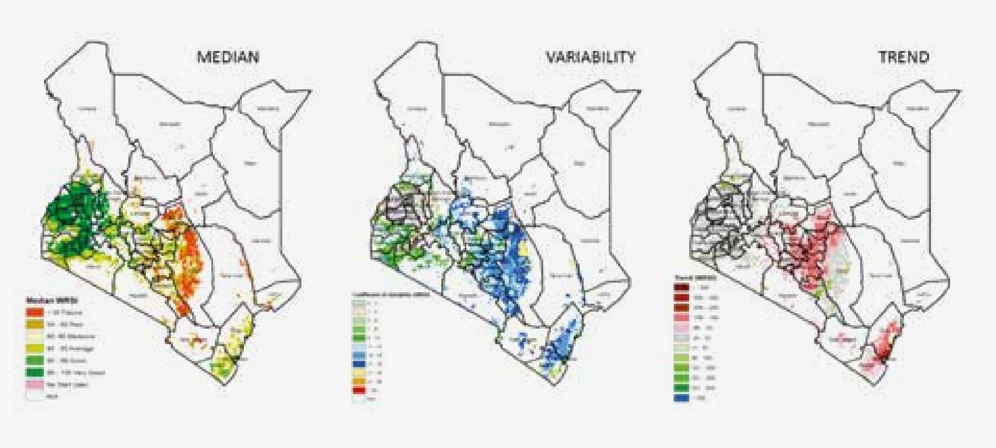
The Geospatial Water Requirement Satisfaction Index (GeoWRSI) crop model outputs were used to analyse the quality of a cropping season based on the crop's water requirements at its various phenological stages. This was then used to characterize cropping conditions within the delineated crop mask. GeoWRSI is a crop specific model, which incorporates the following as its main inputs (Verdin & Klaver 2002):

- Crop characteristics – crop coefficient (Kc) and its length of growing period;
- Soil characteristics – soil water holding capacity; and
- Prevailing weather conditions – dekadal rainfall and potential evapotranspiration.

Of these inputs, weather is the most variable and the key determinant of crop production (acreage and yield), especially in the predominantly rain fed agricultural areas of Kenya.

The results of this analysis, shown in Figure 10, highlight the long-rainy season, which is the main agricultural production season of Kenya.

Figure 10
GeoWRSI model outputs, analysed to characterize maize and beans trends, within Kenya

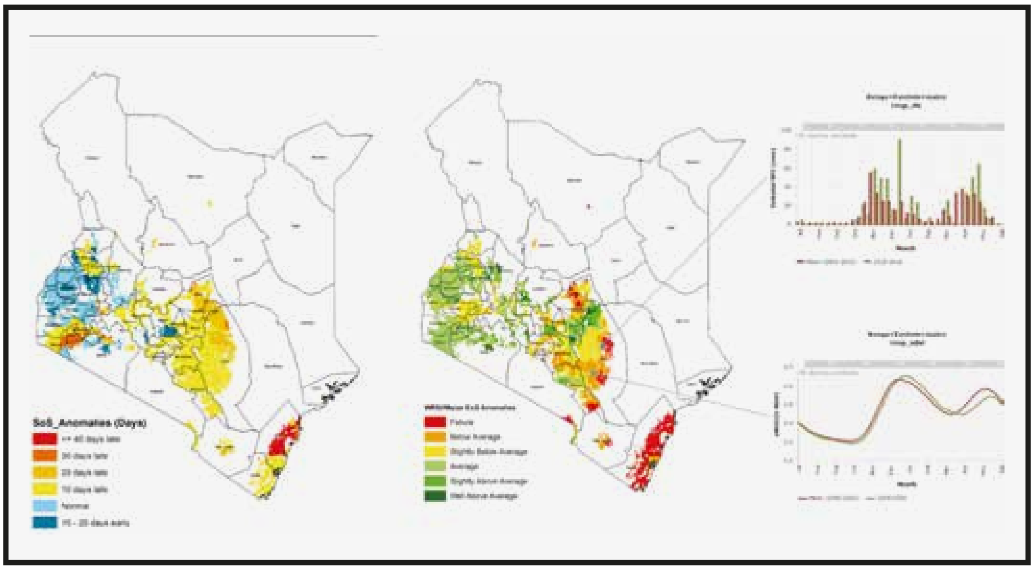


The modelled historical GeoWRSI maize crop trends, provided in the above analysis, depict the following:

- Long-rains cropping season is very important in high to medium production zones and is fairly stable (low variability) and highly predictable, which allows for maize production forecasting in high and parts of medium potential areas, accounting for 70 percent of the national maize production.
- The short-rains cropping season is relatively more stable and reliable compared to long-rains in southeastern marginal agricultural areas of Kenya – in terms of average rainfall amounts, variability and trends.
- The failure rate (60-70 percent) is very high for maize production over the eastern lowlands of Kenya. These high risk areas require more regular and comprehensive crop assessments in order to determine county-level forecasting, which, in turn, will be aggregated to national crop production.
- In recent decades, rainfall variability and declining trends have made maize growing unsuitable in parts of the central and southern rift valley and parts of the central counties of Kenya.

The outputs of the GeoWRSI model also provide Start of Season model outputs as surrogate products, which are very useful in determining the timelines of the season and areas at risk of reduced planted acreage. Figure 11 demonstrates how the significantly delayed start of season and planting dekad resulted in reduced acreage and overall production in 2016 in parts of south eastern Kenya.

Figure 11
2016 Geospatial Water Requirement Satisfaction Index I – start of season and crop performance anomalies and the implication for maize production (acreage harvested and yield) in eastern Kenya.



It is critical at this stage to identify robust crop assessments indicators, which allow for area-specific field assessments and timely and reliable crop estimations.

Statistical analysis of crop production trends and their correlations with remotely sensed products and crop model outputs

Based on defined crop zones in Kenya, in this subsection, the relationship between acreage and yield is summarized with the following readily available remotely sensed products and model outputs at county-level:

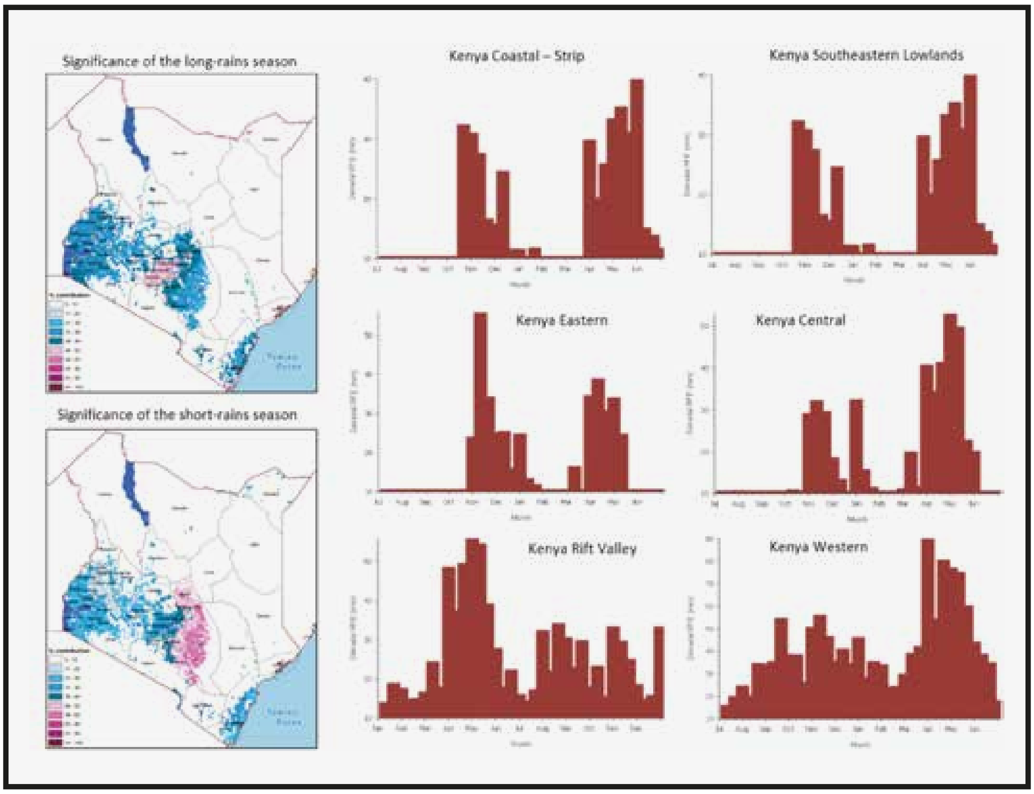
- Rainfall estimates (dekadal CPC/RFE2.0 and Kenya/CHIRPS at 10 and 5km, respectively)
- Normalized Difference Vegetation Indices (pentadal eMODIS/NDVI at 250m), and
- GeoWRSI model outputs (dekadal WRSI images at 10 and 5 km, depending on weather parameters inputs i.e. RFE2.0 or CHIRPs).

Seasonal calendars

As a first step in this statistical analysis, it was imperative to use the available rainfall vegetation indices to generate seasonal cropping calendars to support timely assessments of cropping at different critical phenological stages. Figure 12 shows the cropping calendars in high to low maize production zones based on CPC/RFE2.0. It depicts the following:

- The main rainfall season is the long-rains season (March-May), but its duration extends beyond those months depending on the climatological zones – with the west remaining fairly wet throughout the year .
- The short-rains is very important in the eastern parts of Kenya and account for between 40 and 80 percent of its annual average rainfall amounts, with corresponding 70 percent of its maize production occurring this season.

Figure 12
Spatial and temporal analysis of long- and short-rains seasons and cropping calendars for selected high to low agricultural production zones.



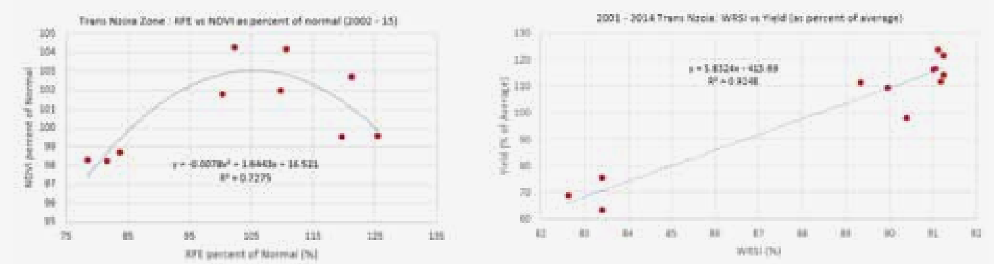
Developing statistical models for crop yield estimations

Recognizing the inherent limitations in field-based crop assessments (subjective but consistent observations) and remotely sensed (indirect but also consistent observations) approaches requires the use of anomalies to statistically correlate these two datasets. This can be done either through the use of percent of average (percent) or anomalies (difference from normal) to reduce the inherent error margins in the observations.

The results are summarized in the maps and tables below based on selected counties, which are classified as high (Trans-Nzoia and Uasin-Gishu) (Figure 13), medium (Nakuru) (Figure 14), and low (Kitui) (Figure 15) maize production zones. The statistical models are intended to assist in identifying robust indicators and models for acreage and yield estimations in support of comprehensive crop assessments and overall production estimation with adequate lead time.

Figure 13

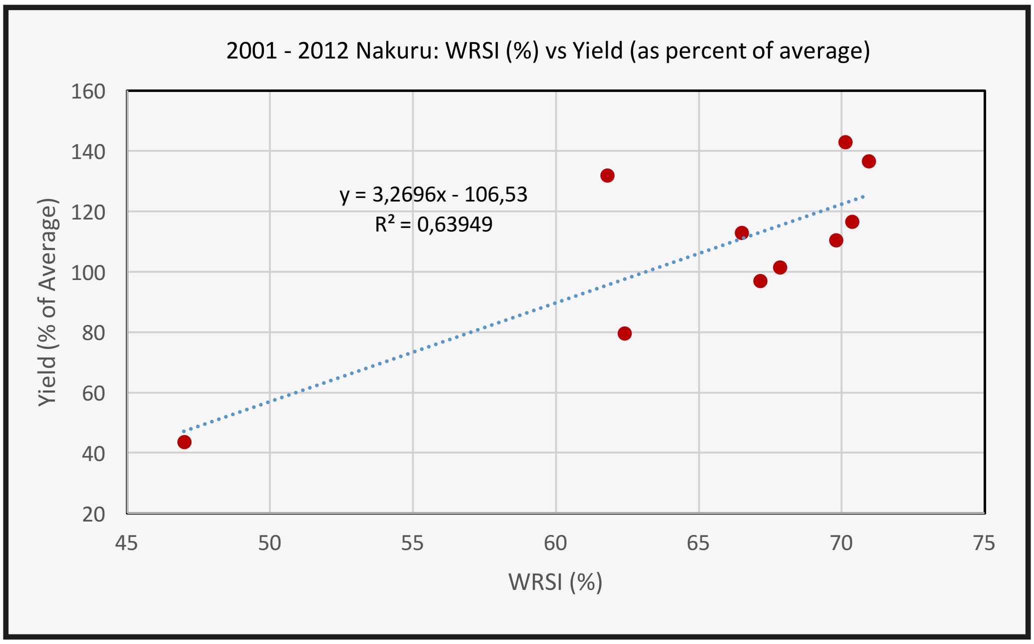
Seasonal statistical correlation analysis for maize yield in Trans-Nzoia – a high production zone, using (a) Rainfall Estimates, (b) eMODIS/ NDVI, and, (c) WRSI/Maize conditions during the long-rains season



The results show high correlation between WRSI/maize crop performance at the end of the season with maize yield as percentage average (percent) in the past 15 years. The average yield in Trans-Nzoia is about 3.1 MT/Ha, with low coefficient of variability, which guarantees good predictability despite the limited datasets. The rainfall estimate (RFE) vs. NDVI correlation is non-linear, indicative of relatively decreasing NDVI values (with corresponding implications on yield) when there is relatively less (<80 percent) or too much rainfall (>125 percent of normal).

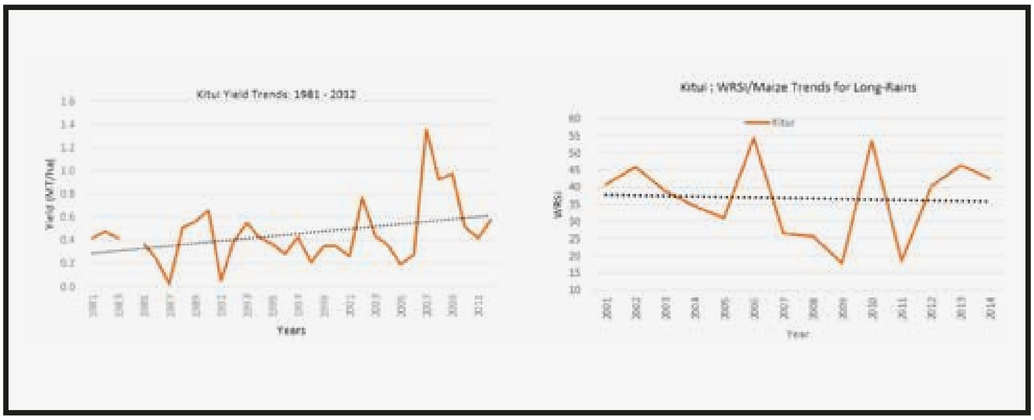
For Nakuru county, the statistical regression model shows good correlation with $r^2 = 0.64$ (Figure 11). However, the analysis is based on limited data in the past decade. Similar to Trans-Nzoia County, the relationship between rainfall and its impacts on vegetation is strong but non-linear, with thresholds for optimum vegetation or cropping conditions between 90 and 105 percent of seasonal rainfall amounts.

Figure 14
Seasonal statistical correlation analysis for maize yield in Nakuru, a medium production zone using WRSI/Maize conditions during the long-rains season.



It is evident that there is no strong correlation between the yield in Kitui and WRSI (percent). A closer look at the trends (Figure 15) show that the field observations depict increasing yield while WRSI shows declining (percent) values corresponding to decreasing rainfall trends during the long-rains season. The yield data for 1984 seemed to be an outlier and was therefore removed from the analysis.

Figure 15
Seasonal statistical trends analysis for maize yield vs. WRSI in Kitui County, a low production zone using WRSI/Maize conditions during the long-rains season.

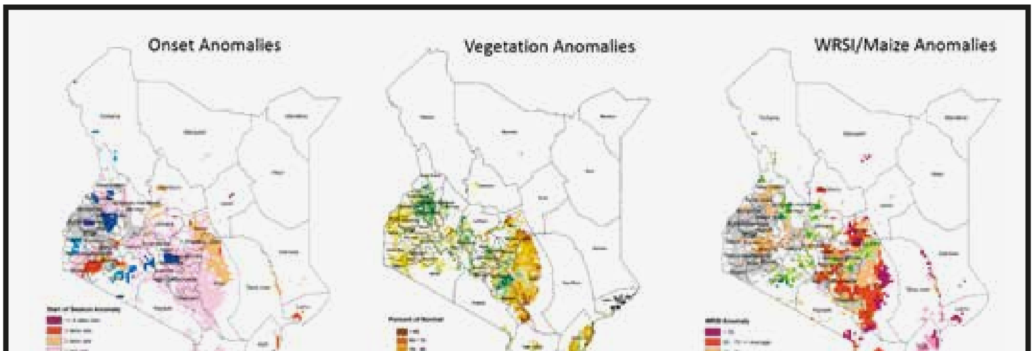


Overall, the results of the analysis above demonstrate that GeoWRSI and NDVI provide invaluable information, which can inform the multistage crop assessments and forecasting during the seasonal cropping calendar. The results of the analysis show that:

- Pre-season crop production forecasting can leverage on development of potential cropping scenarios – based on analog years to generate historical GeoWRSI model outputs and to compare with historical crop production statistics. This is an important preliminary step that allows for indicative crop production prospects (acreage and yield) and also allows for the identification of crop zones at risk of poor or crop failure;
- At the start of the season, RFE, NDVI and WRSI provide useful indicators on the start of season, approximation on area planted, and areas of concern for field assessments;
- Midseason assessments are informed by the quality of the cropping season, in terms of vegetation and crop performance, and allow for an audit of the cropped area and crop establishment and potential yield;
- The flowering and tasseling stage is perhaps the most critical stage for assessing crop production prospects, two thirds through the season, when the crop models become more stable with the crop having passed its critical phenological stage. Rigorous field assessments are advised at this stage, coupled with a statistical model estimation of both yield and acreage; and
- Post-harvest assessments are an important inclusion for end of season and final crop production estimation and for assessing the overall efficacy of the approach in generating timely crop production estimation.

In summary, these remotely sensed indicators show promise in providing convergence of evidence for areas at risk of crop production losses, as illustrated in Figure 16. Significant yield losses were reported in areas with significantly lower WRSI anomalies of less than 50 percent (crop failures) and no-start (>252 percent). The same applies for reduced harvested acreage areas shown through WSRI and NDVI anomalies (< 80 percent of normal).

Figure 16
2016 Convergence of evidence on crop production prospects based on GeoWRSI and eMODIS/NDVI anomalies.

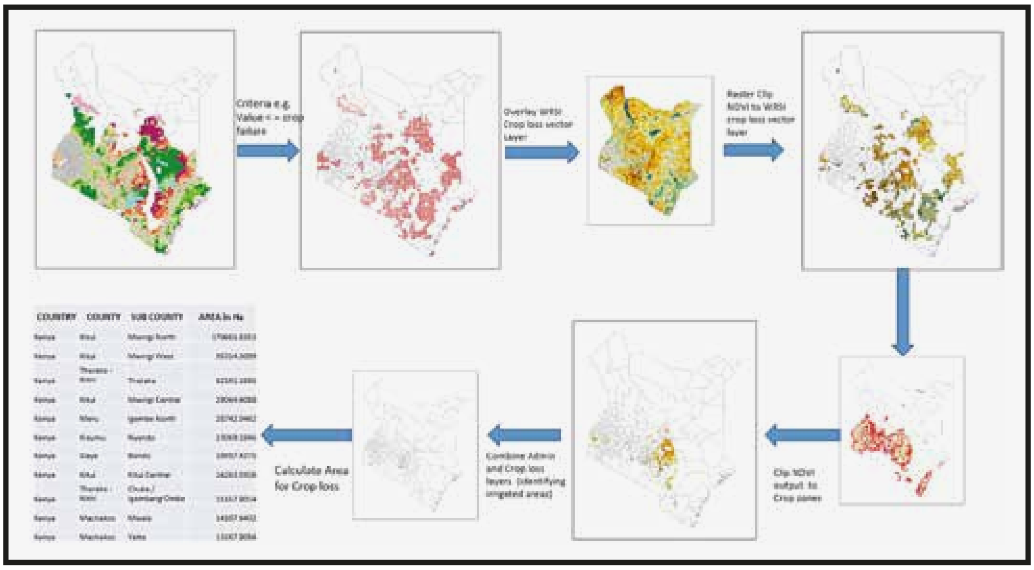


It is against this analysis that a preliminary approach of estimating harvested crop is developed by first computing the following:

- Acreage at risk of total crop losses based on WRSI thresholds of 50 percent < WRSI Anomalies < 252 percent.
- Overlaying corresponding NDVI anomalies and determining thresholds for crop failures based on these geospatially integrated layers and also comparing them with thresholds determined using the statistical analysis, discussed above.

Figure 17 shows the stepwise computation of crop acreage estimation using WRSI and eMODIS/NDVI images at the end of a cropping season.

Figure 17
Stepwise computation of crop acreage estimation using WRSI and eMODIS/NDVI images at the end of a cropping season



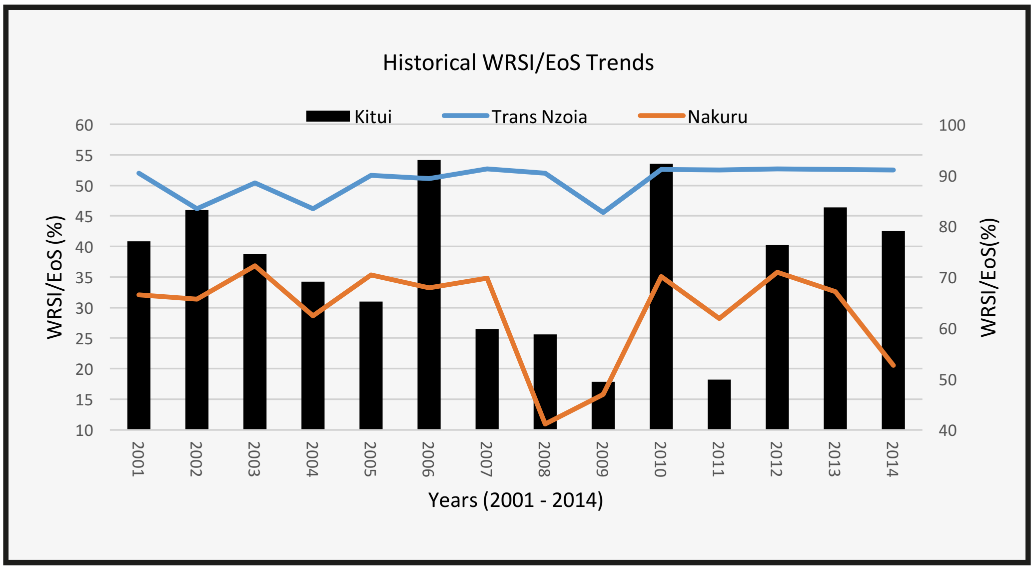
The computed loss in harvested acreage can help to cross check the subjective crop loss assessments provided by Ministry of Agriculture of Kenya, and during instances of dispute, it could form a basis for post-harvest assessments and provide useful information on how best to fine-tune the proposed approach.

Impacts of large-scale climatic drivers (El Niño–Southern Oscillation and Indian Ocean Dipole) on crop production in Kenya

Finally, it was considered worthwhile to analyse WRSI historical trends to see if the model is able to identify historical drought, normal and wet-years and how those trends could be related to large-scale climatic drivers, such as the El Niño-Southern Oscillation and the Indian Ocean Dipole modes. Figure 18 shows the El Niño years of 2006 and 2010 with higher seasonal WRSI values associated with increased maize production. Similarly, for the drought years of 2008-2009 and 2011 that were associated with La- Niña, there was marked decline

in WRSI values. In between this period, there was variability in WRSI values in Kitui because of high inter-seasonal rainfall variability attributed to the transitory nature of the Indian Ocean Dipole.

Figure 18
Historical WRSI trend analysis for Trans-Nzoia, Nakuru and Kitui, showing the impacts of extreme climatic events - La- Niña- (drought) and El- Niño (wet).



This analysis portrays a very useful application of climatic drivers (El Nin˜o–Southern Oscillation and Indian Ocean Dipole) in forecasting maize crop production in marginal and medium potential areas. High potential areas are less sensitive to changes in climatic drivers, as demonstrated in Figure 18.

3.2.2 Senegal statistical analysis

Country context

Senegal is between latitudes 12°8′ and 16°4′N and longitudes 11°21′ and 17°32′ W and stretches over 196,710 km² (FAO), with a total population estimated at 13.5 million people in 2013[1], of which more than half (55 percent) live in rural areas. The country shares borders with Mauritania in the north, Mali in the east, Guinea and Guinea Bissau in the south and the Atlantic Ocean in the west. Most of the country lies in the Sahel drought-prone region. Rainfall occurs from June to October and is characterized by irregularities in time and in space. The agricultural subsector contributed 7.26 percent to the national GDP over the period 2009-2013 and still remains a key subsector. It employs 73.8 percent of the rural

[1] Source : ANSD, RGPHAE, December 2013

population according to the last population census (RGPHAE 2013). The sector is dominated by small-scale family farms with small cultivated plots (about 98 percent of the plots do not exceed five ha). Agriculture is a family activity that mainly depends on rainfall (less than 3 percent of the harvested land is irrigated).

Overall, the annual cultivated area is about 2.5 million hectares, which represents 65 percent of the national territory. Cereals are the main crops and as such, land use is proportional to the importance of each cereal, which is as follows: millet/sorghum (about one million ha with an average yield of 0.6 t/ha), rice (96000 ha to 2.3 t/ha) and maize (70 000 ha to 0.9 t/ha). Groundnut is the major cash crop (910,000 ha to 0.8 t/ha) and its products are used in households and processing units.

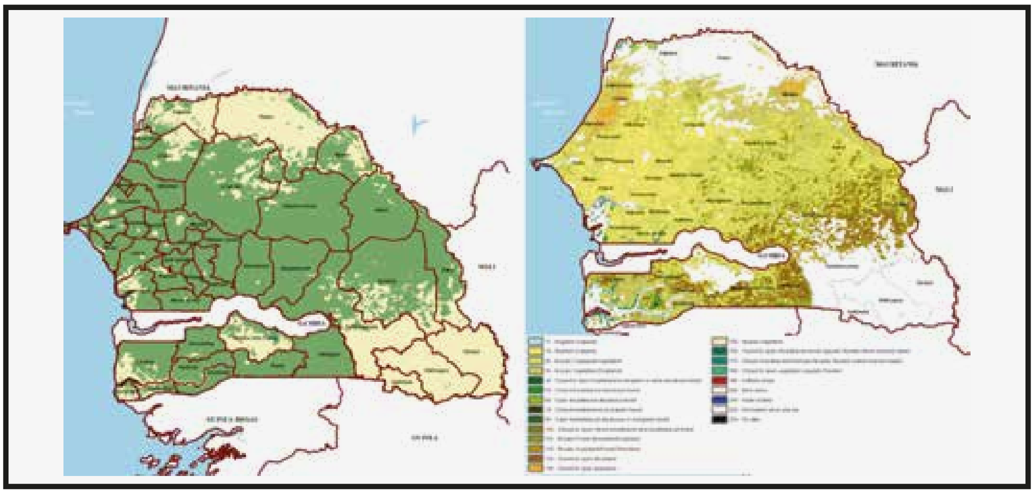
The country meets 70 percent of its food requirements through cereals although it is challenged by a structural deficit in domestic production. In fact, cereal requirement coverage rates ranged from 32 percent in 2007 to 65 percent in 2009. The country imports cereals to fill the gap. However, its rice dependency ratio decreased from 82 percent in 2009 to 67 percent in 2013. This downward trend may be explained by the national effort to promote local production following the 2008 food crisis (World Bank 2013; IFPRI 2015).

Senegal baselines: staple crop zones

This section of the report replicates the same approach used for Kenya in defining crop baselines and related attributes as well as the statistical crop models for analyses of data from Senegal.

Senegal baselines were generated from the FAO/GLCN/Africover dataset. It is important to note that the country depends on millet as the main staple food crop. Figure 19 shows the generalized millet crop zones and subnational administrative boundaries in the country.

Figure 19
Senegal Crop Zones based on International Livestock Research Institute I and Global Land Cover (2009) maps



Climatic trends

As illustrated in Figure 20, the average annual rainfall distribution spatial patterns within the delineated crop zones shows highest rainfall areas over regions bordering Gambia (> 800mm), medium rainfall areas over central Senegal (400- 600mm), and lowest rainfall amounts in northern Senegal, ranging between 200— 400mm. The average annual rainfall variability spatial patterns are based on coefficient of variability (CV percent). These show relatively high rainfall variability in northern Senegal (CV>20 percent), which also receives low rainfall amounts. There is, however, no declining rainfall trends, rather increasing rainfall indications in few locations, especially over eastern and western Senegal (50 – 100 mm/ decade). The rest of the cropping zones show fairly stable conditions.

Figure 20
Senegal annual rainfall distribution patterns and trends – amounts, variability and trends and potential impacts on rain fed cropping conditions

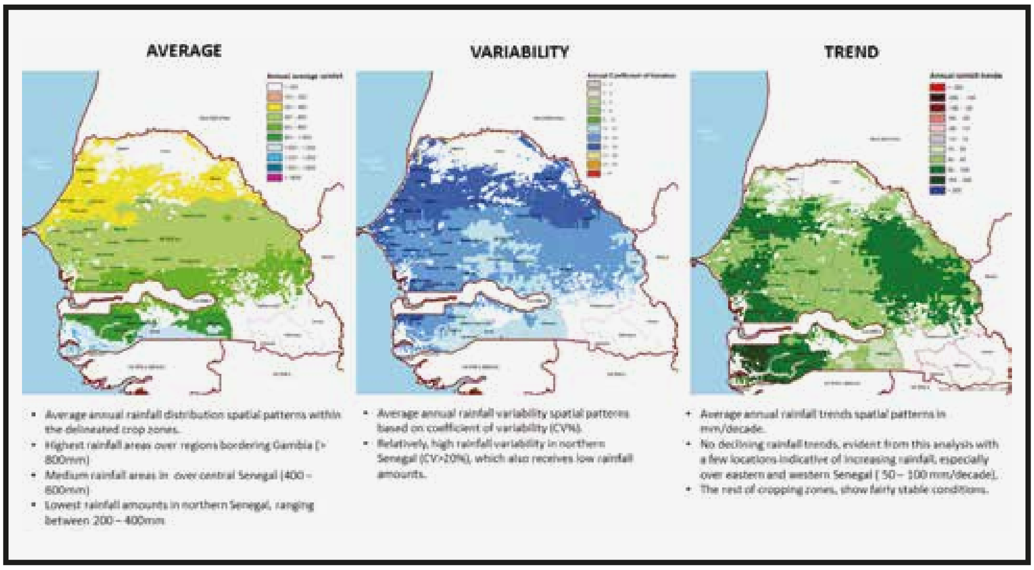
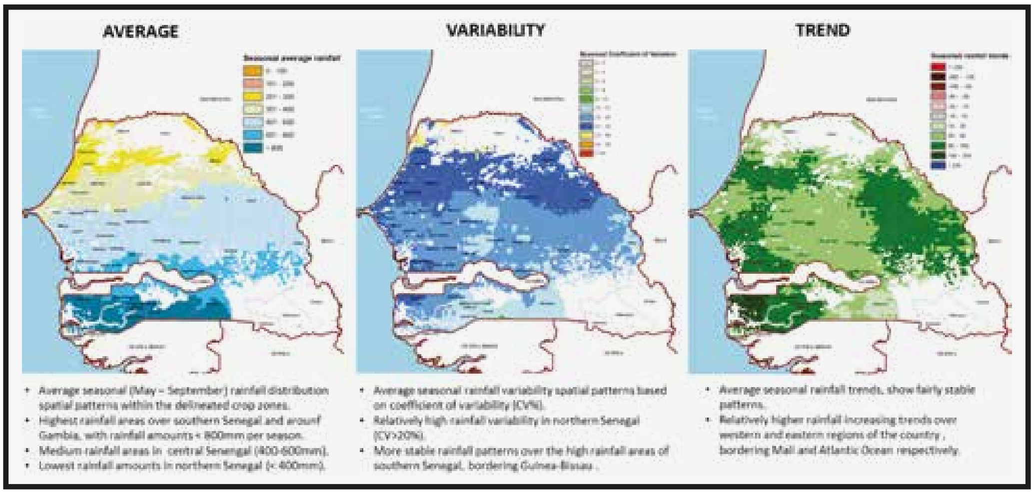


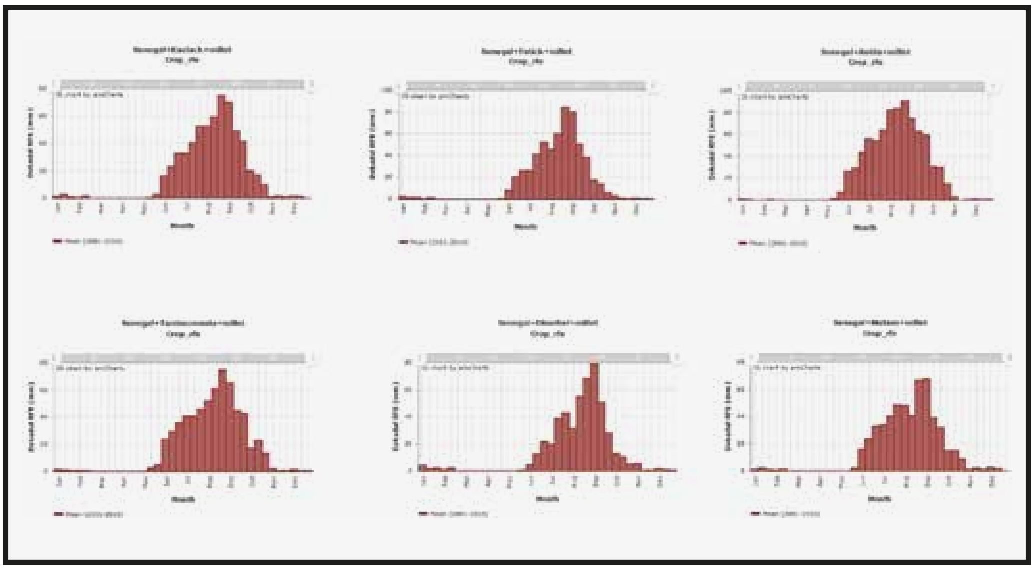
Figure 21 depicts the average seasonal (May-September) spatial rainfall distribution patterns within the delineated crop zones. The highest rainfall areas are over southern Senegal and around Gambia, with rainfall amounts < 800 mm per season. Medium rainfall areas are in central Senegal (400-600 mm) while lowest rainfall amounts are in northern Senegal (< 400mm).

Figure 21
Seasonal rainfall distribution patterns –average amounts, variability and trend



Senegal depends on rain fed agricultural production. The characterization of the crop was therefore undertaken using rainfall and vegetation indices. Figure 22 shows the rainfall patterns across representative zones in the country. In most parts of the country, rainfall is unimodal, often starting in late June and ending in September, with the peak period during the months of August and September. The dry season is from December to April.

Figure 22
Uni-modal rainfall patterns across Senegal



A time-series analysis of eMODIS/NDVI anomalies images (percent of normal) from 2001 to 2015, showing that the NDVI values are generally near average for most regions of Senegal, apart from Thies and Diuorbel, where it experienced recurrent below average NDVI, mostly in 2002, 2004, 2007 and 2014. Figures 23 depicts the overview of vegetation conditions presented as a percent of normal while Figure 24 illustrates the time-series analysis for selected regions in Senegal.

Figure 23
eMODIS/NDVI anomalies image (percent of normal): 2001 - 2015.

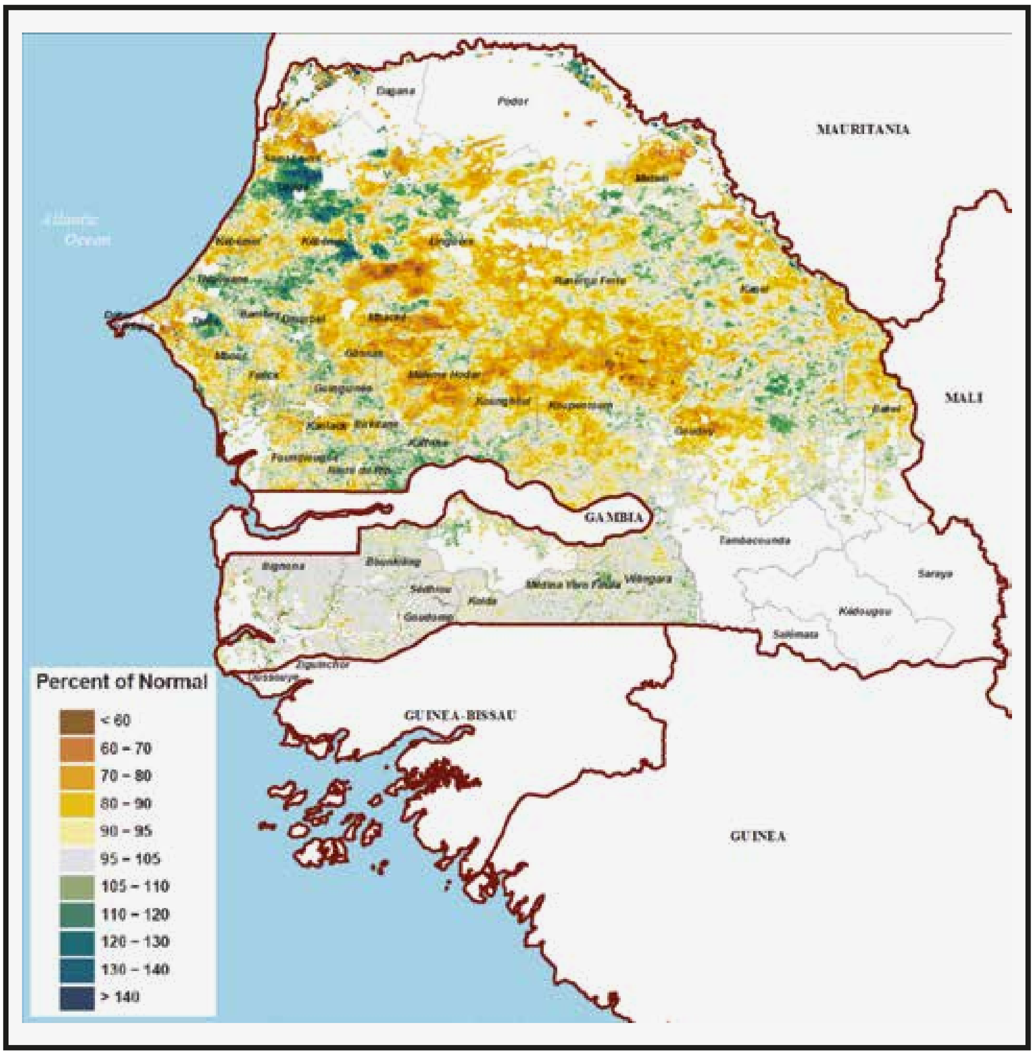
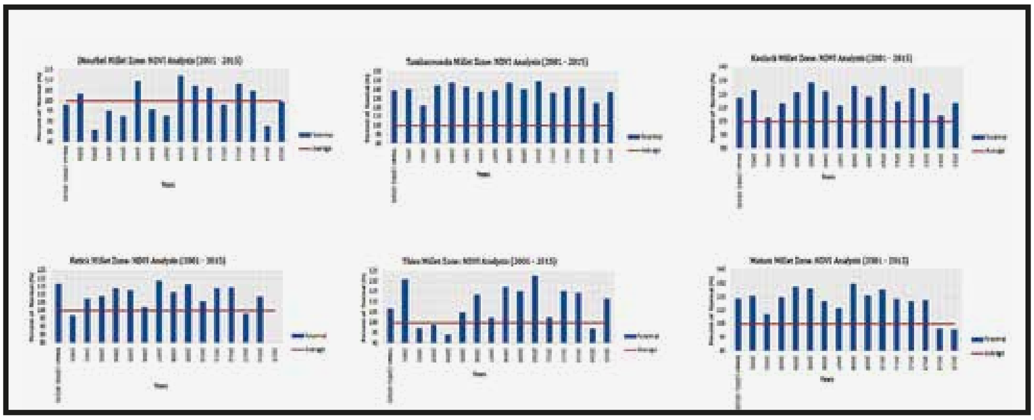
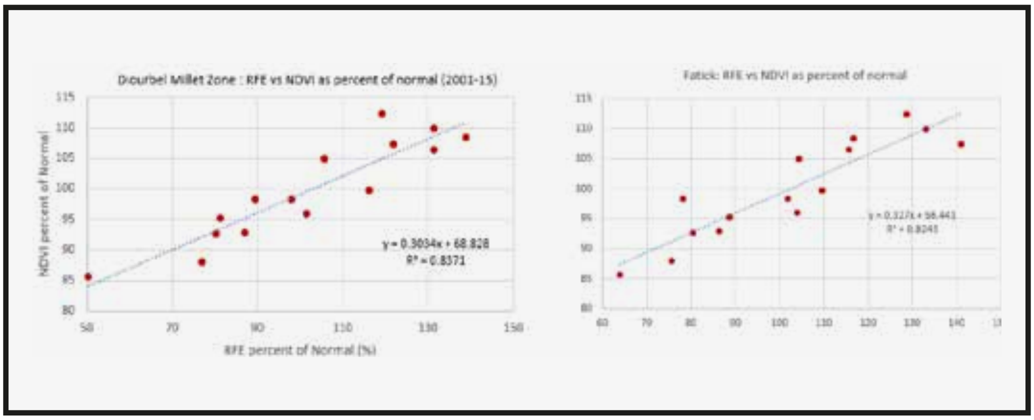


Figure 24
Time-series analysis of eMODIS/NDVI anomalies from 2001 to 2015.



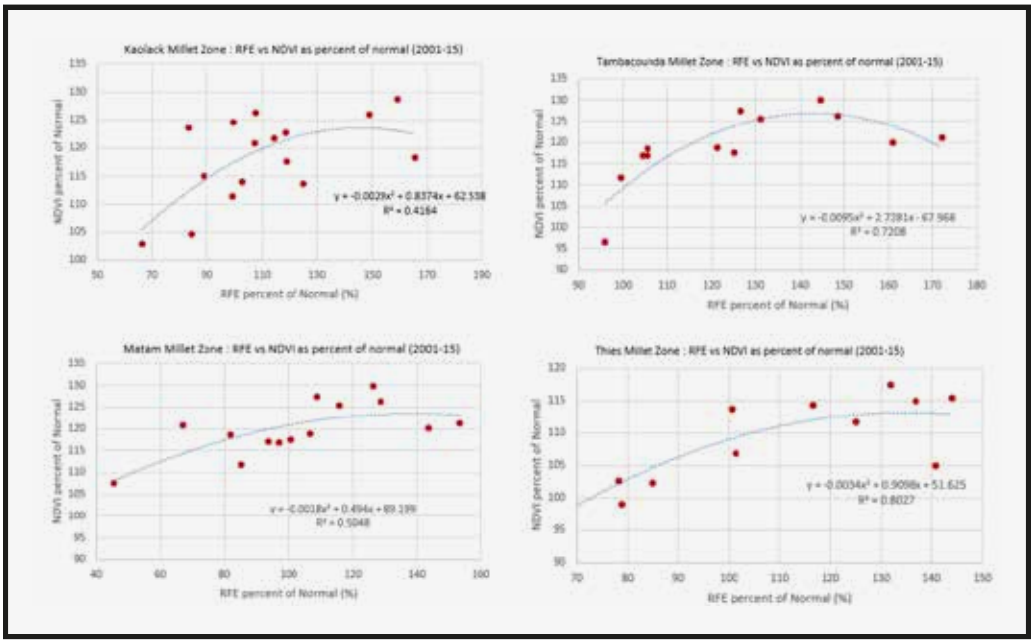
As shown in Figure 25, there is a strong linear correlation of about r2=0.8 between rainfall performance and vegetation conditions in the cropped regions of Diourbel and Fatick.

Figure 25
Linear statistical correlation between rainfall and vegetation conditions in Diourbel and Fatick regions of Senegal.



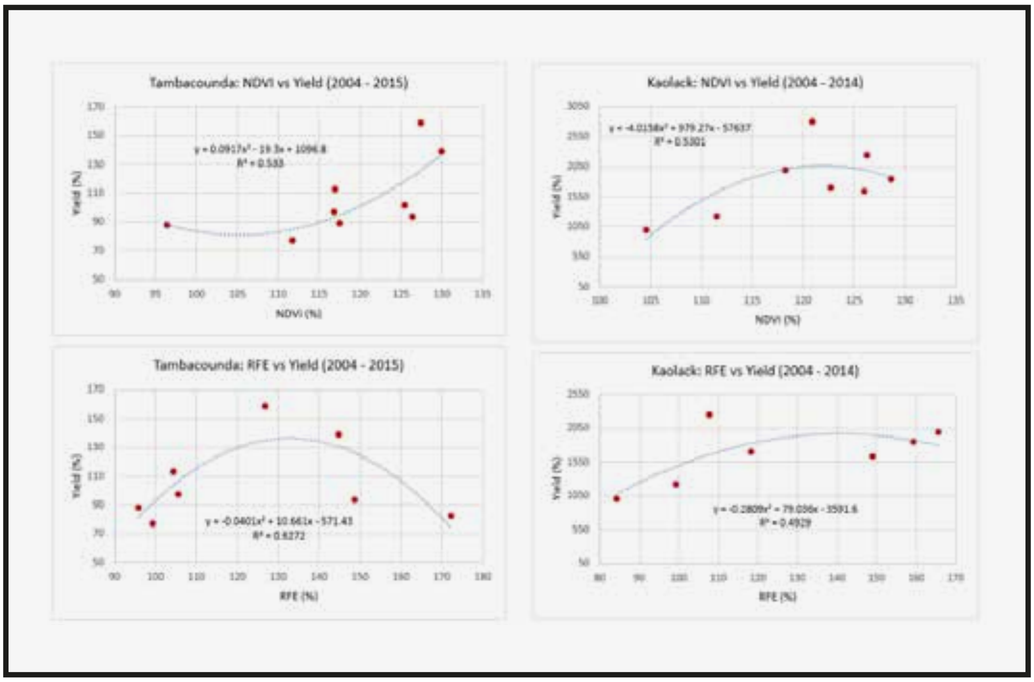
Whereas the Tambacounda and Thies millet zones depict a strong non-linear correlation of r2 >0.7, the correlation between rainfall and vegetation condition is non-linear but relatively weaker in Kaolack and Matam region, as shown in Figure 26.

Figure 26
Non-linear statistical correlation between rainfall and vegetation conditions in Kaolack, Tambacounda, Thies and Matam regions of Senegal.



The findings of the above analysis imply that rainfall performance can be used to estimate vegetation conditions within the millet growing areas of Senegal. In addition, the analysis on NDVI versus yield as percent of normal is also quite encouraging in terms of developing crop yield estimates based on readily available pentadal eMODIS/NDVI during the crop growing season of the country. Figure 27 contains a summary of the statistical relations between yield, rainfall and NDVI for two selected millet zones – Tambacounda and Kaolack.

Figure 27
Statistical regression models for yield vs. RFE and NDVI for selected millet zones in Senegal.

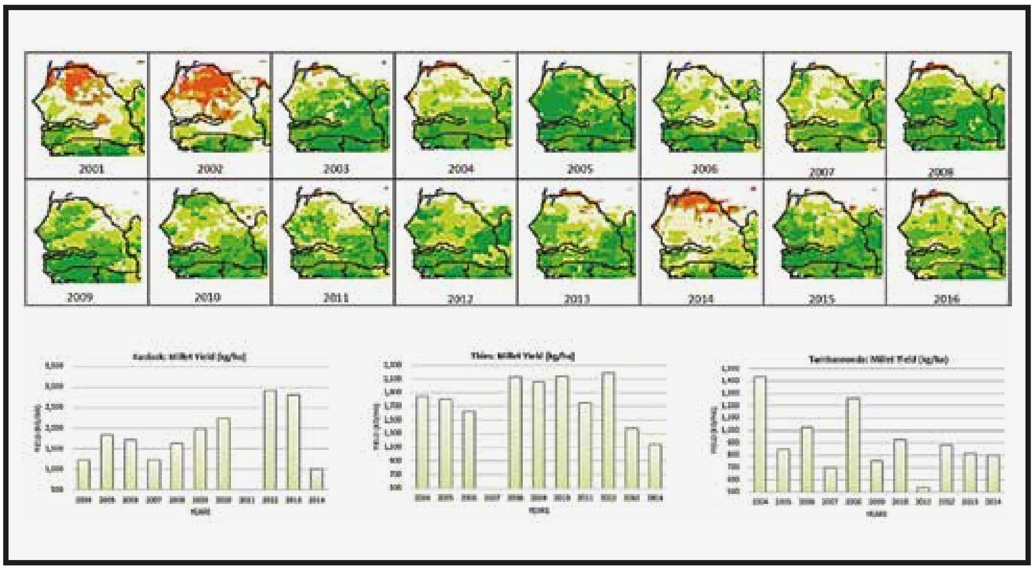


Simulated millet crop simulated trends

In Senegal, the historical millet crop simulated trends based on WRSI model depicts the spatial variability of crop performance across the country. The northern and parts of the central regions of Senegal showing high inter-seasonal variability, which can be related to field based yield observations and areas worst affected as noted in Longa, Saint Louis, Lingeure, Matam, the southern regions of Tambacounda, Kanel and N. Bakel. However, the crop performance over the southern regions of Senegal is stable because of the relatively high and steady rainfall regimes. The reliable millet cropping areas are Bignona, Sedhious, Boukling, Medina, Kolda and Vilngara and most parts of Bakel.

Figure 28 shows the historical WRSImillet trends for millet from 2001 to 2016 with the 2001/2002, 2004, 2006/2007, 2011 and 2014 being some of the worst cropping years in Senegal, especially in the northern and central regions of the country. The time-series analysis of millet yield in Tambacounda, Thies and Kaolack confirms these trends. The Thies region is relatively a better millet cropping region of Senegal with higher average yields of about 1,800 kg/ha compared to Tambacounda with an average of about 900kg/ha, which has recurrent poor or mediocre crop performance, as shown in the maps and graphs below.

Figure 28
Historical trends of WRSI and yield trends (for Millet), in selected regions of Senegal; Kaolack, Thies and Tambacounda.



3.2.3 Zimbabwe statistical analysis

Country context

Zimbabwe is in the southern part of Africa between latitudes 15° 30″ and 22° 30 south of the Equator and longitudes 25° 00″ and 33° 10″ east of the Greenwich Meridian. The country is landlocked and is bordered by Mozambique to the east, South Africa to the south, Botswana to the west and Zambia to the north and north-west. The country's total land area is approximately 390 757 km2. The Country is divided into ten administrative provinces; Bulawayo, Harare, Manicaland, Mashonaland Central, Mashonaland East, Mashonaland West, Masvingo, Matabeleland North, Matabeleland South and Midlands.

Zimbabwe enjoys tropical climate moderated by altitude with a unimodal rainfall pattern which occurs between October through March. The period between December to February is the peak of the rainfall season.

The country's agricultural production accounts for 14.0 percent of its GDP while industry and services contribute 28.5 percent and 59 percent, respectively. Of the 42 percent of the country's total agricultural land, only 10.9 percent is arable (World Bank 2014).

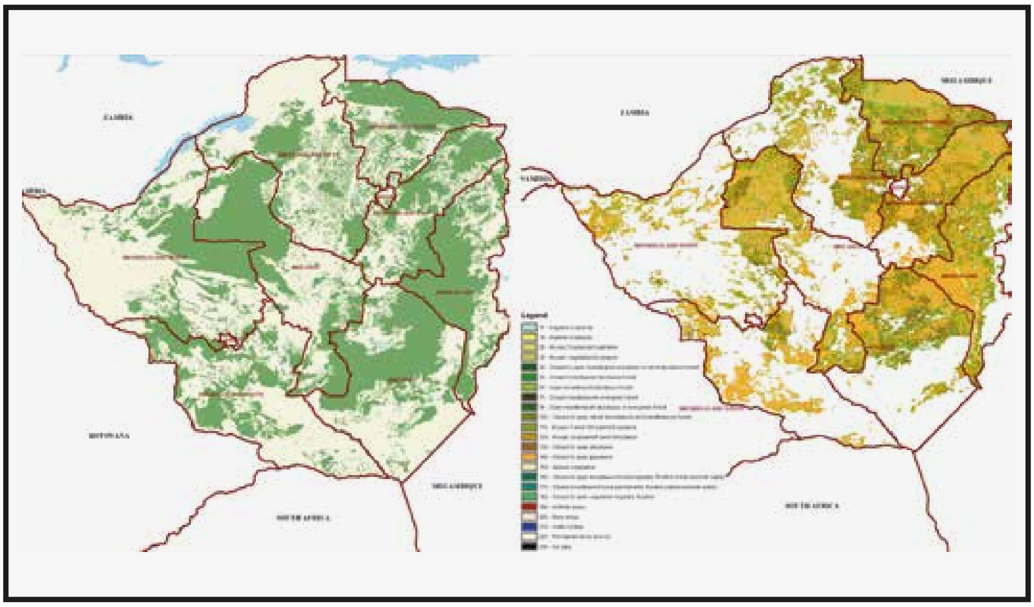
Zimbabwe baselines: staple crop zones

This section of the report replicates the same approach used for Kenya in defining crop baselines and related attributes as well as statistical crop models for the analyses of data on Zimbabwe.

Zimbabwe baselines were generated from the country's 2008 land cover dataset. It is important to note that maize and beans are the main staple crops. Figure 29 shows the generalized maize and beans crop zones and subnational administrative boundaries in the country.

The agricultural statistics data provided by the Ministry of Agriculture was from 2011 to 2015 and therefore statistically limited. However, there is good historical NDVI, RFE and WRSI data for Zimbabwe that allows correlation analysis among them but with caution when applied to statistics from the Ministry because of the limited statistical sample.

Figure 29
Zimbabwe Crop Zones based on on International Livestock Research Institute and Global Land Cover (2009) maps



Climatic trends

As illustrated in Figure 30, the average annual rainfall distribution spatial patterns within the delineated crop zones depict the highest rainfall areas to be over eastern Zimbabwe – eastern and central Mashonaland and parts of Manicaland (< 800mm), the medium rainfall areas are in Midlands and Masvingo and the lowest rainfall amounts are in southern Matabeland (> 400mm). The average annual rainfall variability spatial patterns are based on coefficient of variability and generally show high rainfall variability in all parts of the croplands (< 20 percent), with relatively more stable rainfall in northern Midlands and north Matabele land (>15 percent). The average annual spatial rainfall trends patterns show that there is no declining rainfall trend that is evident from this analysis, with a few locations indicative of increasing rainfall, especially over northern Masvingo and parts of east, west and central Mashanoland (50-100 mm/decade).

Figure 30
Zimbabwe annual rainfall distribution patterns and trends – amounts, variability and trends and potential impacts on rain fed cropping conditions

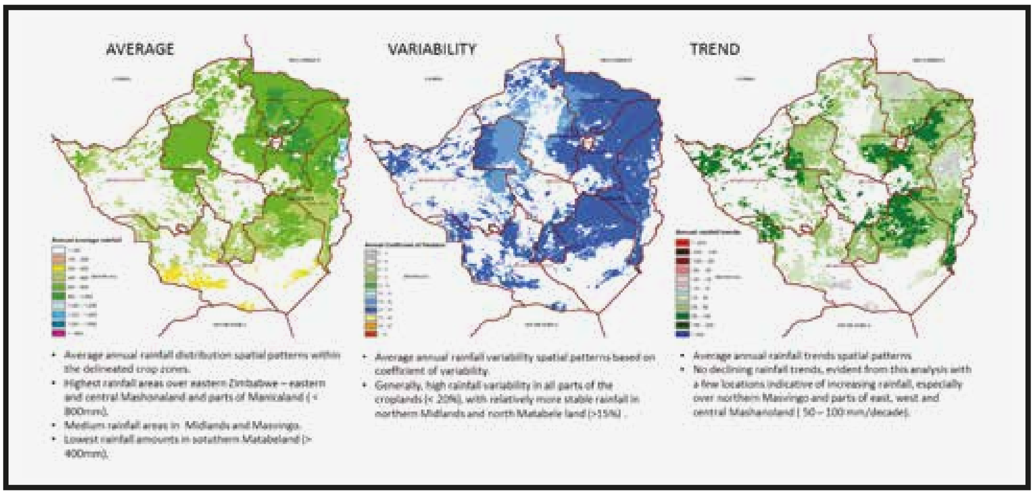
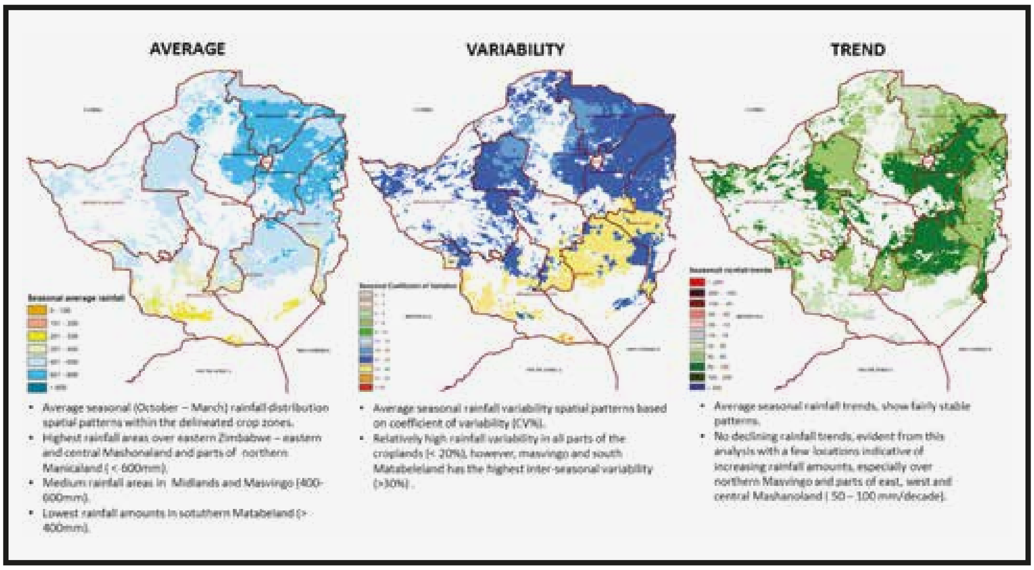


Figure 31 shows the average seasonal (October-March) rainfall distribution spatial patterns within the delineated crop zones as follows: the highest rainfall areas are over eastern Zimbabwe – eastern and central Mashonaland and parts of northern Manicaland (< 600mm); the medium rainfall areas are in Midlands and Masvingo (400-600mm); and the lowest rainfall amounts in southern Matabeland (> 400mm). The average seasonal rainfall variability spatial patterns are based on coefficient of variability (CV percent) and show relatively high rainfall variability in all parts of the croplands (< 20 percent) with Masvingo and south Matabeleland however, showing the highest inter-seasonal variability (> 30 percent). The average seasonal rainfall trends show fairly stable patterns with no declining rainfall trends evident from this analysis. A few locations are indicative of increasing rainfall amounts, especially over northern Masvingo and parts of east, west and central Mashanoland (50-100 mm/decade).

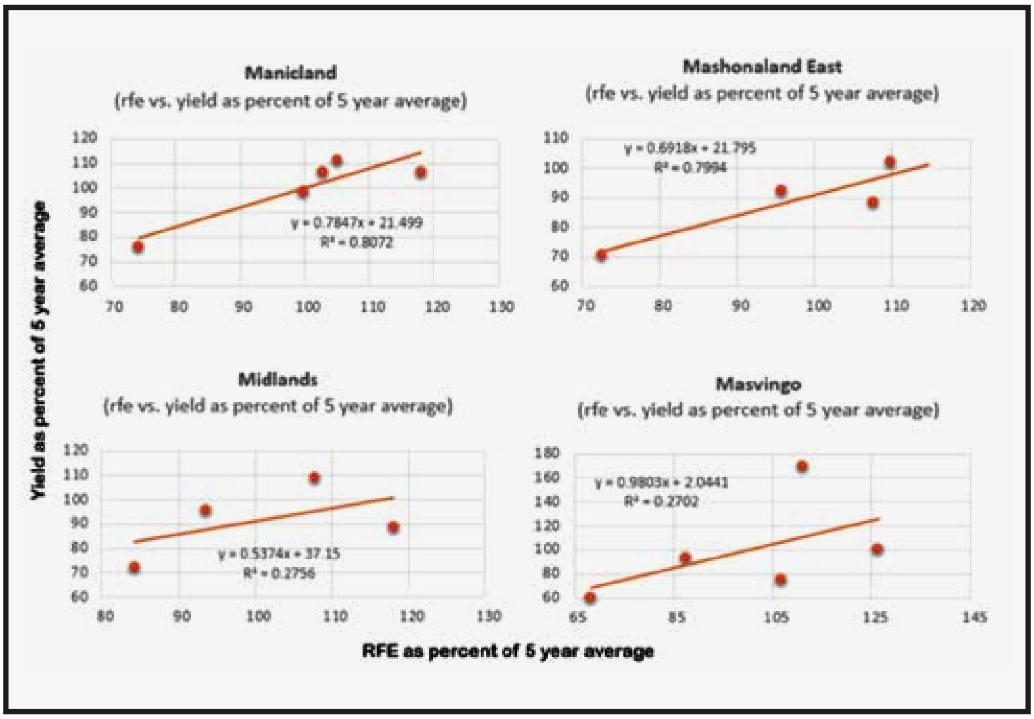
Figure 31
Zimbabwe seasonal rainfall distribution patterns and trends – amounts, variability and trends and potential impacts on rain fed cropping conditions



Zimbabwe agricultural production is largely rain fed and relies on the October–March rainfall season, with its peak in rainfall amounts from December to February. Figure 31 depicts the seasonal rainfall patterns across all the major maize cropping areas of Zimbabwe, namely Manicaland, Mashonaland, Midlands and Masvingo.

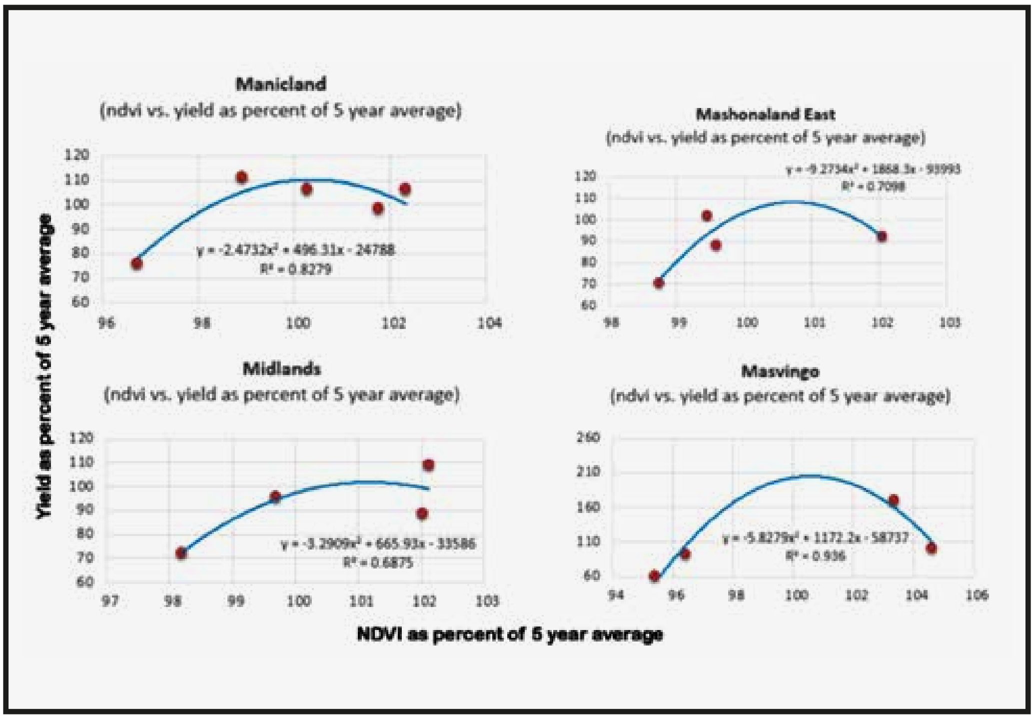
Zimbabwe currently has limited quality agriculture production data. Based on the dataset provided through FAO contacts in the country, the statistical correlations were undertaken within the delineated cropped zones to preliminarily establish the relationship between rainfall and yield and further, between NDVI/vegetation with yield. Figure 32 shows a positive linear correlation between rainfall and yield in Manicaland, East Mashonaland, Midlands and Masvingo, with qualitative correlations of r2 of between 0.2 and 0.8. A larger historical sample of yield data would have provided a more robust regression model.

Figure 32
Seasonal rainfall patterns across the major maize cropping areas of Zimbabwe, namely Manicland, Mashonaland, Midlands and Masvingo



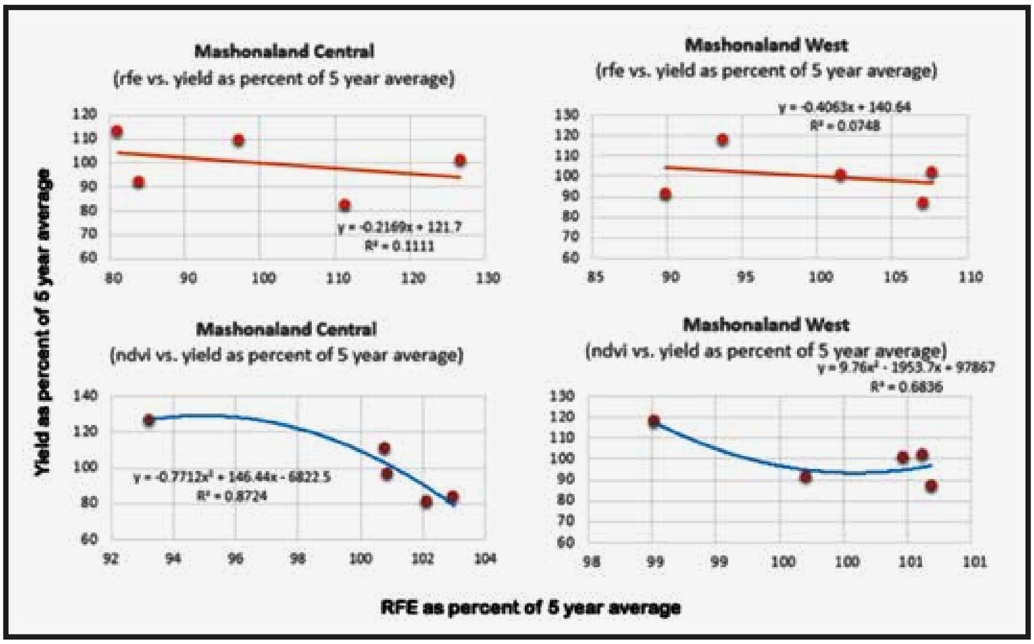
Similarly, for the vegetation (NDVI) vs yield, there is strong, but, non-linear correlation in Manicland, East Mashonaland, Midlands and Masvingo, as shown in Figure 33. This is indicative of optimal vegetation conditions that translate to favorable yield prospects. This model could assist in developing a set of thresholds in support of crop yield estimation in these key cropping areas.

Figure 33
Correlation between rainfall and yield in Minicland, East Mashonaland, Midlands and Masvingo



Meanwhile, central and west Mashonaland show negative correlation between yield and rainfall. This could be related to recent Ministry of Agriculture statistics and will require further investigation with longer term maize production statistics. Figure 34 shows the negative correlations.

Figure 34
Negative linear correlation between rainfall and NDVI and yield in Mashonaland Central and Mashonaland West



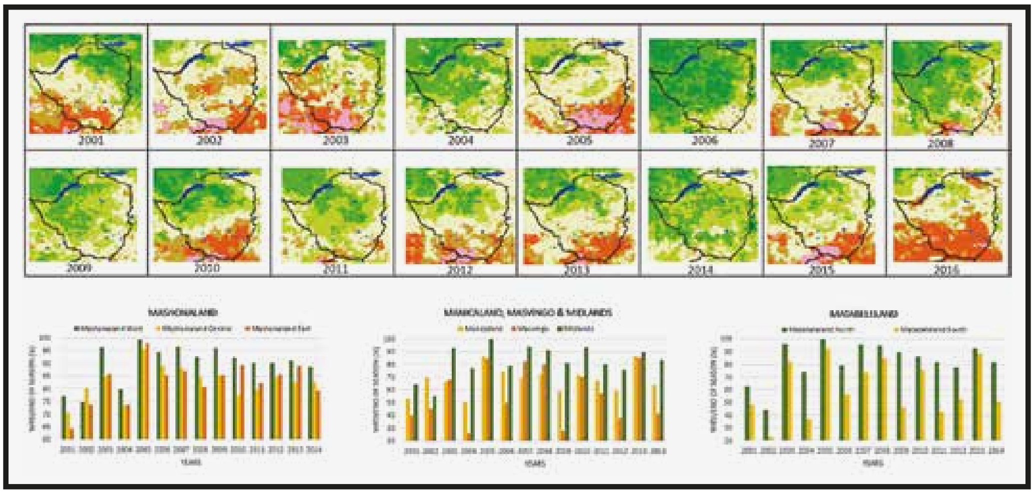
In these same maize zones, the correlation between NDVI and yield is also non-linear, but with a negative trend, raising doubts on the quality of the yield datasets used in the analysis. This concern in statistical correlation is depicted in Figure 34. It could also be explained because of the agricultural changes that occurred recently, which resulted in decreased yield because of the lack of farm inputs and other related socio-economic constraints.

Simulated maize trends

In Zimbabwe, the historical maize crop performance trends based on the WRSI mode, show the spatial and temporal variability of the overall crop performance (2001-2016) across the country. The southern and parts of the central regions of Zimbabwe shows high inter-seasonal variability and recurrent poor to crop failure conditions, which can be related to field-based yield observations, with the worst affected regions being Masvingo, southwest Manicaland and south Matabeleland. However, the crop performance over parts of the central and northern regions of Zimbabwe are relatively stable because of the relatively high and stable rainfall regimes. The reliable maize cropping areas are Mashonaland and Midlands.

Figure 35 shows the historical WRSI/maize trends from 2001 to 2016, with the 2001, 2002, 2003, 2005, 2007, 2010, 2012, 2013, 2015/16 appearing to be some of the worst cropping years for southern Zimbabwe. The time-series analysis of maize performance, which can be related to yield, provide detailed comparisons across Zimbabwe's cropping regions.

Figure 35
Historical WRSI/maize trends from 2001 to -2016

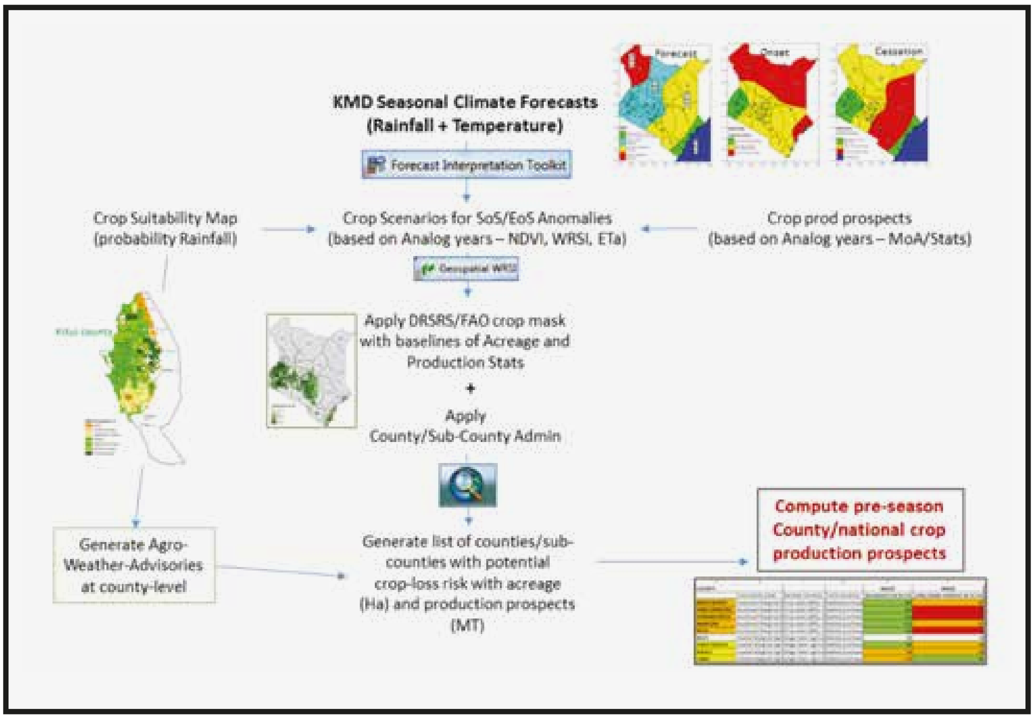


4

Pre-Season agricultural production forecasts based on consensus seasonal rainfall and temperature forecasts

Key steps for this include interpreting seasonal forecasts with determined thresholds (based on crop – specific requirements) to identify areas of potential risk of failure at the subnational level (for example, county, district or province) and analyse potential impact(s) on crop production. Subsequently, analogue years are used to generate likely agricultural production outlook scenarios and assess potential impact on cropping conditions (ministry of agriculture, WRSI, NDVI and actual evapotranspiration (Eta) anomalies. These will help in identifying areas of potential risk of failure at the subnational level; in conducting analysis of the potential impact on crop production at the sub-national level; carrying out a comparison with Ministry of Agriculture agricultural statistics for selected analogue years; considering potential limitations or opportunities associated with crop production (new seed varieties, flood risks, policy and, farm input prices, among others), and generating subnational to national level crop production prospects based on discussions with national and subnational meteorological services and ministry of agriculture extension officers. This process is summarized in Figure 36.

Figure 36
Preseason agricultural production forecasts: flow diagram showing datasets, tools and analysis

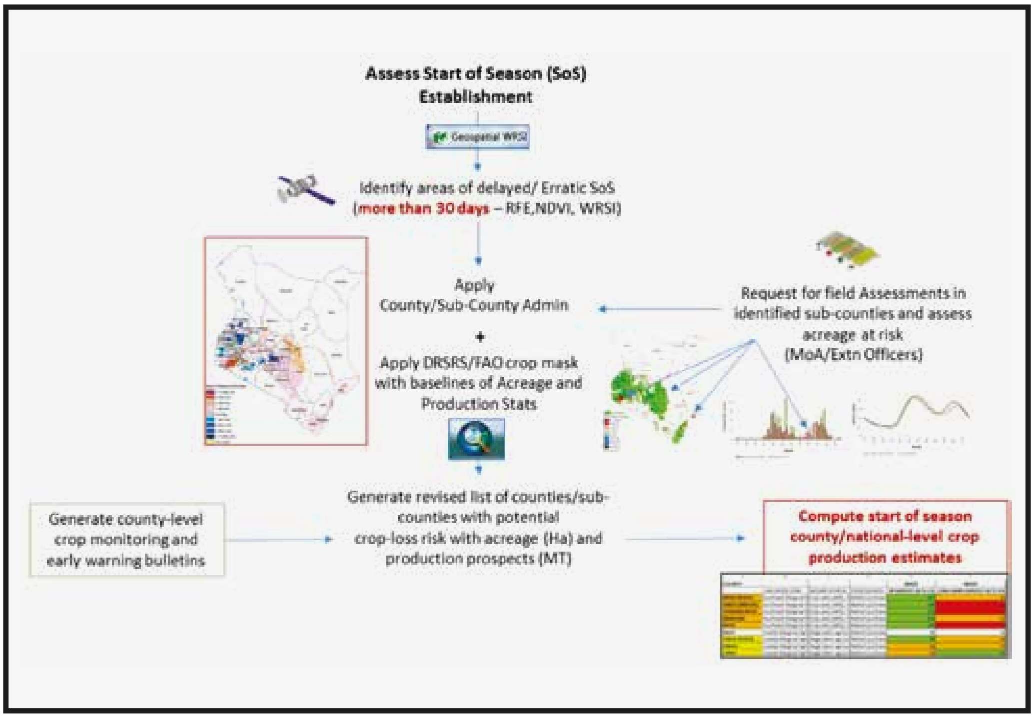


5

Assessing the establishment of the start of season planting and generating revised agricultural production forecasts

Assessing the establishment of seasonal rains using remote sensing observations and products requires: the identification of areas of significantly delayed onset at the subnational level; use of Landsat/Sentinel-2 to confirm occurrence of land preparation and planting; liaising with the ministry of agriculture extension officers to assess identified areas and other areas and issues; and revision and updating of crop production forecasts at the start of season to help analyse potential crop production prospects at the subnational level and generate aggregated national estimates. This process is summarized in Figure 37.

Figure 37
Start of season – assess establishment of start of season and planted acreage



6

Assessing crop performance and updating agricultural production prospects

Assessing crop establishment and cropping conditions at the subnational level requires: identification of significantly delayed onset at the subnational level; identification of areas of poor cropping conditions; liaising with ministry of agriculture extension officers to assess identified areas and other areas and issues; and revising and updating crop production forecasts at crop establishment that entails analysing potential crop production prospects at the subnational level based on convergence of evidence from field extension officers and remotely sensed products, generating subnational level estimates weighted with available ancillary datasets, such as maize density maps, and finally generating aggregated national-level estimates. This process is summarized in Figures 38 and 39.

Figure 38
he GeoWRSI/Crop model inputs

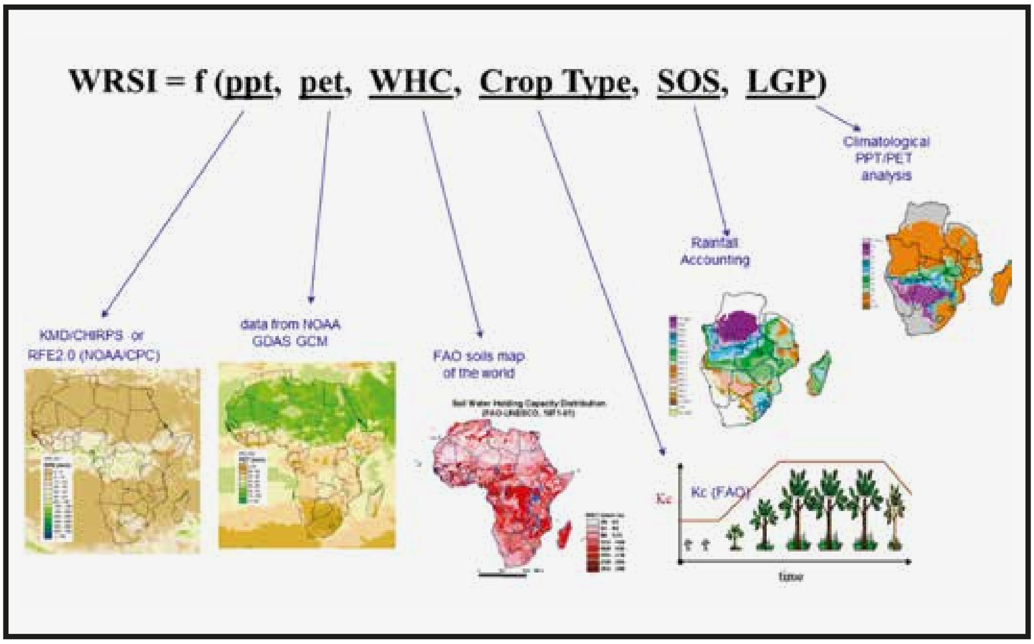
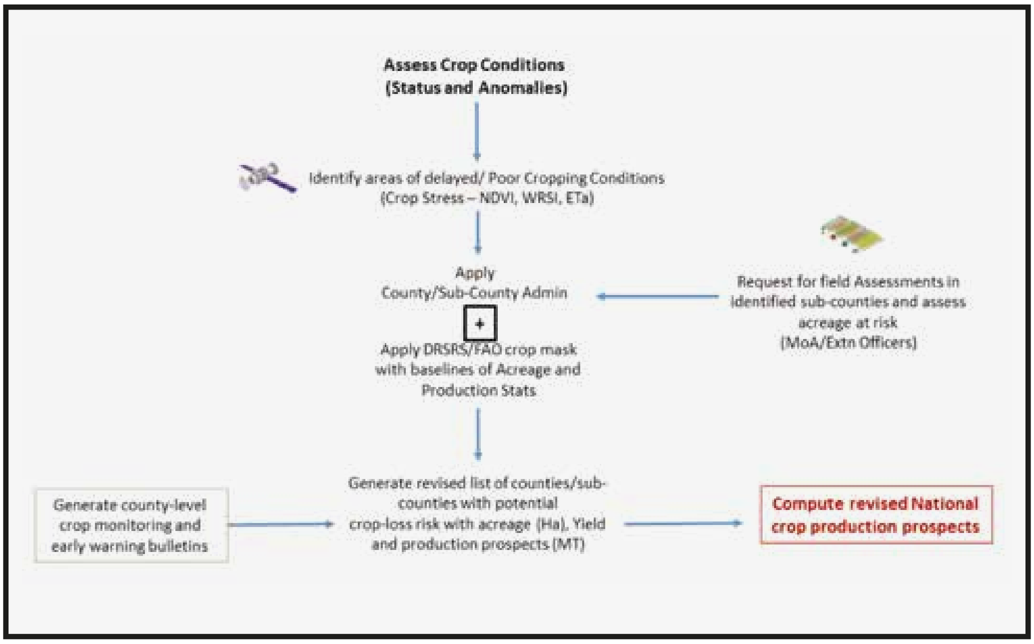


Figure 39
Steps for assessing crop conditions and computing revised national crop production prospects



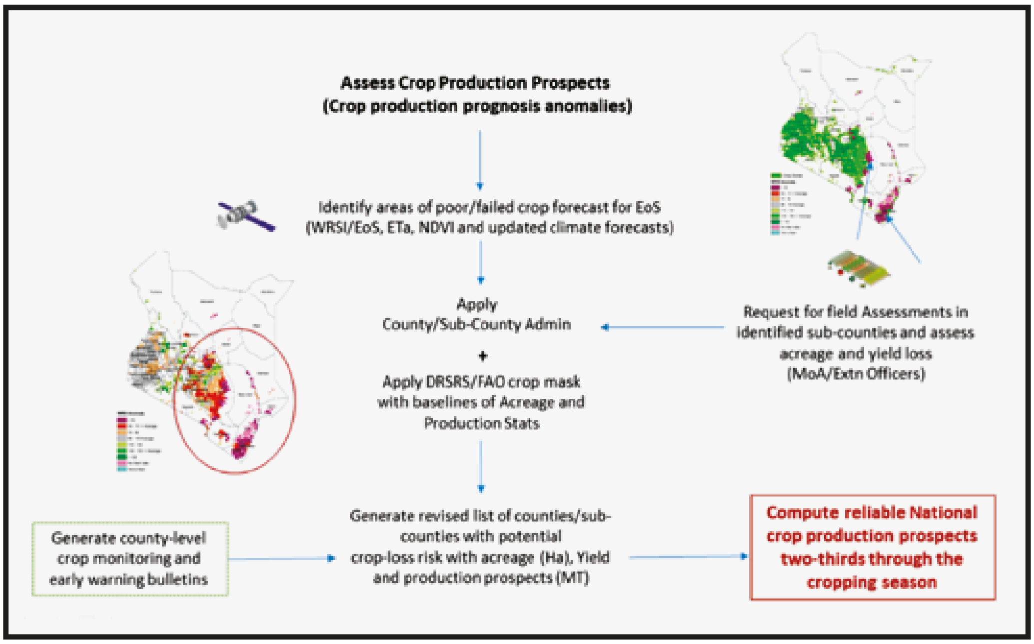
7

Assessing crop maturity conditions and prognosis for end of season to generate reliable agricultural production forecasts

Assessing the cropping conditions at critical stage and undertaking a prognosis for end of season production prospects at the subnational level should be done by: identifying areas of poor or failed cropping conditions; liaising with the ministry of agriculture extension officers to assess identified areas and other areas and issues; assessing potential impact on production prospects, considering reliable seasonal rainfall forecasts for the remainder of the season; and revising and updating crop production forecasts by analysing potential crop production prospects at the subnational level based on convergence of evidence from the ministry of agriculture field extension officers and remote sensing products, generating subnational level estimates weighted with available ancillary datasets, such as maize density maps, generating aggregated national-level estimates, and generating consumption vs. production curves at the county/district to national-level. This process is summarized in Figures 40 and 41.

Figure 40

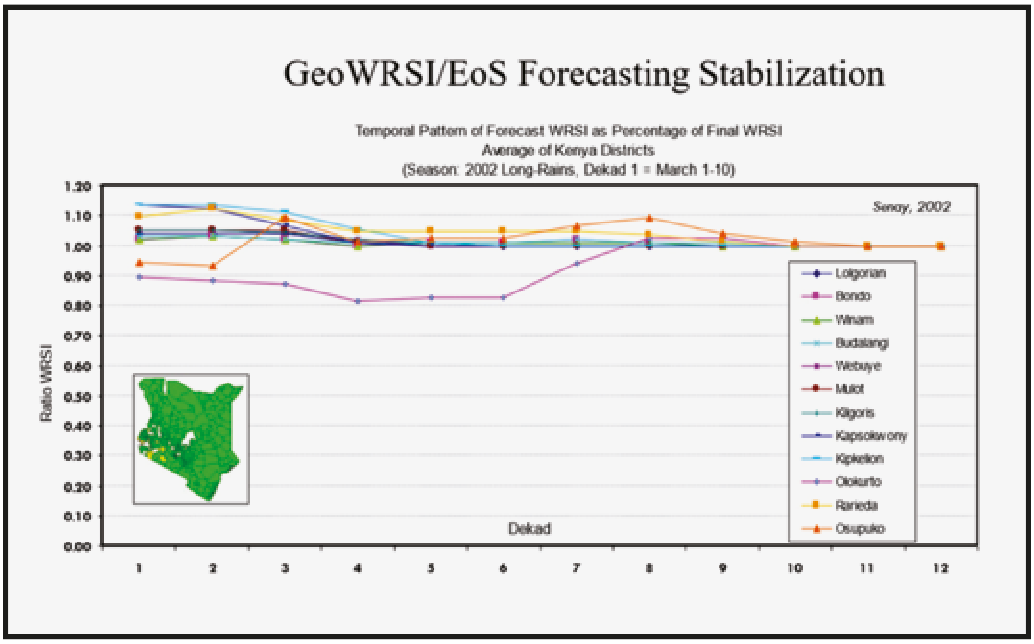
Assess cropping conditions at critical phenological stage and generate reliable production forecasts



GeoWRSI/Crop model forecast stabilization is carried out two thirds through the cropping season to provide adequate lead time for decision-making at the county and national level.

Figure 41

GeoWRSI/end of season forecasting stabilization



8

Assessing overall end of season cropping anomalies and generating final crop production estimates with adequate lead-time

This entails revising and updating the final crop production estimates by: providing final crop production estimates at the subnational level and level of confidence; stating assumptions and areas of potential discrepancy; generating final aggregated national-level estimates; and generating final consumption vs. production curves at the county to national level.

9

Post-season harvest assessments

This entails stakeholders discussing and making recommendations based on challenges and opportunities encountered for the improvements of the current crop production estimation system, and revision of the training approach, manual and datasets.

10

Recommendations

10.1 Recommendations

The following recommendations are based on expert knowledge, reviews conducted in the course of producing the guidelines advanced in this document and consultations held with countries during national workshops and training courses.

i. **Methods currently being used by national governments to generate agricultural statistics and forecasts should be improved**: One issue that stands out is that national governments in the three pilot countries heavily rely on field methods to collect agricultural statistics. Limitations, such as inadequate budgets to support regular and optimal geographical coverage, biases induced by extension officers, lack of adequate planning information to support field surveys were also among the issues cited. To improve on this, governments need to do the following:
   - Adopt robust methods that will ensure regular updating of national crop masks, and better still, for each of the national staples;
   - Incorporate the use of geospatial technologies (GIS, GPS / GNSS, freely available high resolution satellite imagery such as 10m sentinel-2) in their field sampling approaches and methodologies;
   - Incorporate remote sensing products, such as Start of Season (SoS), anomalies, End of Season (EoS), to inform the planning of field surveys and further support analysis and production of agricultural statistics and forecasts
   - Bring onto one national platform all stakeholders engaged in production of agricultural statistics and forecasts in the country
   - Budget adequately for the production of agricultural statistics and forecasts

ii. **Freely available geospatial platforms should be used by national governments to provide a high-level overview of the prevailing conditions before, during and after the growing season**: Various freely available geospatial platforms are available for governments to use to gain a quick understanding of prevailing situations in the country at the subnational to national level with respect to monitoring the agricultural areas before, during and after the growing season. These platforms will help to quickly inform where and how the season is progressing. Such information will then be followed by targeted field missions to ascertain the situation on the ground. Governments should therefore continuously use the following platforms to monitor the season:

- **Global Information and Early Warning System on Food and Agriculture (GIEWS)**: Developed by FAO to monitor the condition of major food crops across the globe to assess production prospects. The portal supports analysis and supplements ground-based information using remote sensing data that can provide valuable insight on water availability and vegetation health during cropping seasons. Parameters monitored include: Agricultural Stress Index (ASI), Vegetation Condition Index (VCI), Vegetation Health Index (VHI), Normalized Difference Vegetation Index (NDVI) anomaly, Estimated Precipitation, Precipitation Anomaly, and Progress of Season. The portal is accessible at http://www.fao.org/giews/earthobservation/index.jsp?lang=en or http://www.fao.org/giews/earthobservation/index.jsp?lang=fr
- **United States Geological Survey FEWS NET Interactive Map Viewer**: Developed by the United States Geological Survey FEWS NET Project to support drought monitoring efforts throughout the world. The portal is part of the Early Warning Focus Area at the United State Geological Survey Earth Resources Observation and Science Centre. The portal monitors five regions, namely Afghanistan, Africa, the Caribbean, Central America and Yemen. It allows users to monitor a cropping season using administrative boundaries or crop mask boundaries. Parameters monitored include Normalized Difference Vegetation Index (NDVI), Cumulative Rainfall, Dekadal Rainfall, and Actual Evapotranspiration. The portal is accessible at: https://earlywarning.usgs.gov/fews/mapviewer/index.php?region=af

iii. **Remote Sensing data, products, tools and methodologies should be embraced by national governments to support the production of agricultural statistics and forecasts at the subnational to national level**. There are various freely available remote sensing datasets, products, tools, and methodologies available, which national governments can access to use to support the production of agricultural statistics and forecasts. The remote sensing datasets available for free range from low resolution (e.g. eMODIS, Proba-V, Sentinel-3, etc.), to medium resolution (e.g. 100m Proba-V) to high resolution (Sentinel-1, Sentinel-2, Landsat, among others). are also available in optical or synthetic aperture radar (SAR) data formats. There are also freely available tools (e. g. GeoWRSI) and GIS software (e.g. Quantum GIS), which that can be downloaded from the Internet and used to support processing of remote sensing and field data. National governments therefore need to take advantage of these freely available data by investing in requisite computer infrastructure, such as hardware and Internet connectivity, to support the production of agricultural statistics and forecasts. The following are links from which the free remote sensing datasets, tools, and software can be accessed:

- **Low resolution remote sensing datasets and products**:
  - eMODIS NDVI data (https://earlywarning.usgs.gov/fews/datadownloads)
  - Rainfall (RFE) data (https://earlywarning.usgs.gov/fews/datadownloads/Continental%20Africa/Dekadal%20RFE)
  - Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) data (https://earlywarning.usgs.gov/fews/datadownloads/Global/CHIRPS%202.0)
  - Actual evapotranspiration (ETa) anomaly (https://earlywarning.usgs.gov/fews/datadownloads/Continental%20Africa/ETa%20Anomaly)
  - Potential evapotranspiration (PET) (https://earlywarning.usgs.gov/fews/datadownloads/Global/PET)
  - Proba-V (300m to 1Km resolution) (http://www.vito-eodata.be/PDF/portal/Application.html#Home)
  - Sentinel-3 (https://scihub.copernicus.eu/dhus/#/home)
- Medium resolution RS datasets:
  - Proba-V (100m resolution) (http://www.vito-eodata.be/PDF/portal/Application.html#Home)
- High resolution remote sensing datasets:
  - Sentinel-1 (https://scihub.copernicus.eu/dhus/#/home)
  - Sentinel-2 (https://scihub.copernicus.eu/dhus/#/home)
  - Landsat (http://glovis.usgs.gov/next/)
- Geospatial tools and software:
  - Geospatial Water Requirement Satisfaction Index (GeoWRSI) (http://chg.geog.ucsb.edu/tools/geowrsi/)
  - Quantum GIS (QGIS) (www.qgis.org/en/site/forusers/download.html)

iv. **Countries should pilot the implementation of the these guidelines**: Pursuant to the training conducted in Kenya, Senegal and Zimbabwe on guidelines on the use of available tools, products, methodologies and data to improve agricultural crop production forecasts, the trainees derived an action plan for the countries to begin pilot projects. This action plan aimed at enabling the countries to test, appreciate and review (if applicable) the applicability of the guidelines that include not just the technical aspects but the institutional aspects as well. The three countries agreed to start the pilot project in the 2017 or 2017/18 season. The Governments of Kenya, Senegal and Zimbabwe are therefore urged to support the pilot projects that the trainees envisaged.

v. **Countries should invest in ongoing capacity development for the application of geospatial technologies in agricultural statistics and forecasting**: Continuous capacity development, particularly in human resources and infrastructure is critical for the sustainable application of geospatial technologies by government agencies responsible for agricultural statistics and forecasts. New datasets, products, tools and methodologies continue to be introduced, hence the need for national governments to continue to invest in staff training and upgrading of their computer and Internet infrastructure. Governments should therefore adequately budget for capacity development activities in the area of agricultural statistics and forecasts.

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